

LIQUID-SOLIDS SEPARATION IN
DOMESTIC WASTE
WITH A CATIONIC POLYELECTROLYTE

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Comparison of the highest molecular weight Cat Floc polymer with Purifloc C-31 and Primafluc C-7 for coagulation-flocculation of raw sewage showed that the three polymers were equally effective in the removal of BOD and suspended solids.

Studies on coagulation-flocculation of two industrial waste waters resulted in the removal of essentially all of the suspended matter. A significant reduction in the COD and BOD in these waste waters was realized due to removal of the suspended matter. The residual COD and BOD were due to the presence of residual dissolved organic matter.

Flocculation and settling of activated sludge with three polymer molecular weights showed there was a significant difference in the settling rates, with the higher molecular weight polymer consistently giving faster settling rates.

Further experiments on vacuum filtration of anaerobically digested sludge, using both the Buchner funnel and filter leaf tests showed Cat Floc to be an effective sludge dewatering agent capable of increasing the yield of vacuum filters and lowering the sludge specific resistance with low polymer dosages. The higher molecular weight

sample consistently produced higher vacuum filter yields and higher reductions in specific resistance.

It is concluded that Cat Flocc is highly effective for coagulation-flocculation of domestic waste water, increasing settling rates of activated sludge, and dewatering anaerobically digested sludge. It is further concluded that the higher molecular weight polymer is more effective in all phases of domestic waste water treatment.

I. INTRODUCTION

Domestic sewage is composed of a wide variety of both dissolved and suspended organic and inorganic matter. The removal of these organic and inorganic materials is the purpose of sewage treatment and is desirable for the protection of public health and preservation of our country's lakes and streams. In the past the popularity of chemical treatment of domestic sewage has undergone several cycles of rising and waning. As a sole process for treatment of domestic sewage, chemical treatment possesses the inherent limitation of being less effective for the removal of soluble putrescible matter than biological processes.¹ The most widely used coagulants for chemical coagulation of waste water are salts of iron and aluminum. The use of these chemicals creates many problems, including high dosage requirements and difficulty in treatment and disposal of large sludge volumes.

In the last several years the introduction of synthetic organic polyelectrolytes has seen their application in many diversified fields. Soil scientists^{2,3,4,5} have

found organic polyelectrolytes to be very effective as soil conditioners for improving the porosity of soils. The mining industry has used polyelectrolytes for many years in ore dressing processes. In the water treatment industry they have been used mainly as coagulant aids^{6,7} while in the sewage treatment field polyelectrolytes have been used largely for sludge dewatering.⁸

Although the use of organic polyelectrolytes for liquid-solid separation has become increasingly important in recent years and a large number of water and waste treatment specialists and chemical producers are loudly advocating their use, the availability of laboratory data concerning basic mechanisms and over-all efficiencies is practically nil.

With the exception of the unpublished results of Kim⁹ concerned mainly with the destabilization of kaolinite clay suspensions with various anionic polymers used in conjunction with alum, the work of Cohen et al.⁶ on the use of cationic, anionic, and nonionic polymers as coagulant aids in removing turbidity from water, the extensive work of Kane, La Mer, et al.,^{10,11,12,13,14,15,16,17,18,19,20,21,22,23} and an excellent work by Birkner²⁴ on the destabilization of

dilute clay suspensions with labeled polymers, most of the research work on polyelectrolytes for water and waste water treatment has been done by major chemical producers, who have closely guarded their results for proprietary reasons. In reviewing the literature, especially for waste treatment, it was found that most of the papers have been authored by personnel of these chemical producers, who report on plant scale tests of their polymers in vague although favorable terms and present little useful data.

The present investigation is an attempt to present basic laboratory data on the over-all efficiency and effect of molecular weight of a particular cationic polymer for coagulation-flocculation of raw sewage, settling of activated sludge, and vacuum filtration of anaerobically digested sludge.

II. THEORY

Coagulation-Flocculation

Sewage Composition

The waste products found in domestic sewage are a mixture of highly complex inorganic-organic materials partly dissolved and partly in suspension. The sources of these waste products are so diverse, encompassing every human activity, that it is not possible to accurately describe sewage or to present the composition in other than qualitative terms.

In the treatment of raw sewage with polyelectrolytes, the over-all objective is complete liquid-solid separation. The main concern is the separation of colloidal and supracolloidal particles having a diameter of between 10 angstroms and 100 microns. Particles having a diameter of less than 10 angstroms may be considered to be in a soluble phase not amenable to coagulation, and particles with diameters larger than 100 microns may be considered to be settleable or floatable. Although only the colloidal and

supracolloidal particles are amenable to chemical coagulation, they represent a large percentage of the biodegradable matter in domestic sewage.

Colloids

The colloid chemistry of lyophobic and lyophilic particles is, in fact, the surface chemistry of the dispersed phase, and colloidal dispersions can be understood on this basis. Sols are historically divided into two major classes of colloidal systems: namely, lyophobic and lyophilic colloids. If the attraction between the colloidal particles and the dispersing medium is small, the colloid is termed lyophobic. If the attraction between the colloidal particles and the dispersing medium is large, the colloid is termed lyophilic.²⁵ When water systems are discussed, the terms hydrophobic and hydrophilic replace the terms lyophobic and lyophilic and, in general, organic colloids are hydrophilic, whereas inorganic colloids are hydrophobic.

The stability of colloidal particles in an aqueous system is attributed to two different phenomena, negative electrical charge and hydration. Sennett and Oliver²⁶ have summarized the historical development of research on the phenomena referred to collectively as electrokinetic effects,

which led to the discovery of the electrical charge on colloidal particles. In the early nineteenth century it was observed that, when a potential difference was maintained across a porous plug of wet sand or clay separating two portions of water, a movement of water occurred from one side of the diaphragm to the other. This phenomenon, now called electroosmosis, is almost always observed when an e.m.f. is applied to electrodes located on opposite sides of a porous diaphragm immersed in water or other liquid. If the flow of liquid is not restricted, it will continue as long as a potential difference is maintained. However, if the flow is restricted, a pressure will build up until it is sufficient to cause a back-flow through the diaphragm that exactly balances the electroosmotic flow.²⁶

Quantitative measurements of electroosmosis were first made about the middle of the nineteenth century to determine the relation between pressure, flow, and applied potential. A few years later it was reasoned that, because a porous object consists essentially of a mass of fine capillaries, electroosmosis should occur in a single capillary tube. This proved to be true. The next historical step was the discovery that, when a liquid is forced to flow through a capillary tube or porous diaphragm, a

potential difference is created; this is the converse of electroosmosis, and the e.m.f. developed is called the streaming potential. It was further shown that the liquid flow in electroosmosis is not necessarily in the same direction as the current flow. These facts led to the hypothesis that the observed effects are caused by the presence of electrically charged layers of opposite sign at the solid-liquid boundary. An applied voltage would therefore cause a relative displacement of the charged layers; the liquid, being free to move, would flow in a direction dependent on the sign of the charge it carried. This hypothesis also explained the streaming potential as the result of a charge displacement caused by forced flow of liquid along the solid surface. A third manifestation of the electrokinetic effect, which was discovered in the latter part of the nineteenth century, was that, when suspended particles are forced to move through a liquid in response to gravity, a potential gradient is generated in the direction of movement. This phenomenon, variously called the Dorn effect, sedimentation potential, centrifugation potential, or migration potential, can also be qualitatively explained by this hypothesis.²⁶

The development of the theory of the electric double layer dates from 1879 and the work of Helmholtz, as reviewed by Taylor,²⁷ who postulated that formation of an electric double layer was of general occurrence at a phase boundary.

Around this time, it was shown that certain lyophobic colloids were rendered unstable and flocculated by the addition of electrolytes, and that multivalent ions had a disproportionate effect in this regard. In 1892, Linder and Picton, as reviewed by Sennett and Oliver,²⁶ made the important observations that the particles in a colloidal sol migrate under the influence of an electric field, indicating that they are electrically charged with respect to the dispersion medium. Determination of the sign of the particle charge from the direction of its movement made it clear that the flocculating effect of electrolytes was determined by the valence of the ion of opposite charge to the sol. This generalization is now called the Schulze-Hardy rule, which states that the precipitating power of a bivalent ion will be 50 to 60 times as great as a monovalent ion and the precipitating power of a trivalent ion will be 600 to 700 times as great as that of a monovalent ion.²⁵

It was later demonstrated that the stability of

lyophobic sols is closely related to their mobility in an electric field; therefore the dependence of colloid stability on the degree of particle charge was established.²⁶ Migration of particles in colloidal suspension in response to an applied electric field was first called cataphoresis, but the more general term electrophoresis is now preferred.

The application of electrophoretic techniques in the field of water treatment has been pioneered by Black et al.^{28,29,30,31,32} and has, as in other fields, proved to be a valuable research tool.

Origin of Primary Charge

According to various authors,^{27,33,34,35} charges located on particles resulting in the establishment of an electrostatic field may result from one, two, or all of three phenomena: (1) the dissociation of reactive groups on the ends of molecules comprising the particle structure, (2) isomorphous substitution, and (3) the preferential adsorption of ions from the solution phase.

For hydrophillic colloid particles the primary charge is generally due to the dissociation of polar groups such as $-\text{COOH}$ and $-\text{NH}_2$. Protein molecules and their hydrolysis products, for example, contain both carboxylic

acid and amino groups. Depending on the pH of an aqueous system, the amino group hydrolyzes and one or both of the groups dissociate. With the central molecular structure represented by the symbol R, the dissociation may be shown as in Fig. 1.

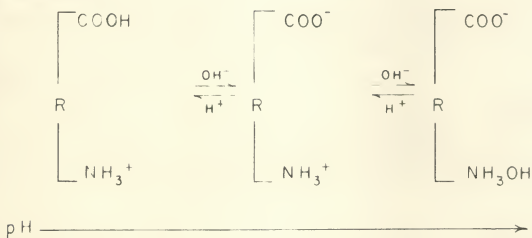


Fig. 1. Dissociation of Carboxyl and Amino Groups (from Rich³⁵).

The degree of ionization of these groups is not greatly influenced by their being attached to the large molecule by covalent bonds, and therefore they behave like the ions of ammonium acetate would behave at the same pH. The carboxyl group tends to ionize at pH values above approximately 4, and the amino group below approximately 10. Therefore in basic solutions protein particles are negatively charged because of NH_2 and COO^- groups, whereas

in acid solutions the particle is positively charged because of the presence of NH_3^+ and COOH groups. Hence there must be a pH, called the isoelectric point, where the positive charges balance the negative charges, resulting in net charge of zero.

Isomorphous substitution and/or preferential adsorption of ions from the solution phase are the primary sources of the charge of hydrophobic colloids such as clays.³³ In clay, isomorphous substitution is the replacement of high valence cations in the clay lattice structure, namely Si^{4+} and Al^{3+} , by lower valence cations. This results in a deficiency of positive charges in the clay lattice structure and the adsorption on the clay surface of cations which are too large to be accommodated within the lattice structure.

The preferential adsorption of ions from the solution phase is a mechanism which is not well understood. However, this mechanism is probably the most significant source of the primary charge on hydrophobic colloidal particles. Since the charge on hydrophobic particles can be reversed by a change in pH, it has been postulated that the primary charge is caused by adsorption of either hydrogen or hydroxyl ions, depending on the relative numbers of each in solution or, more simply, on the pH.

Double Layer Structure

Since any over-all system must remain electrically neutral, a primary charge on a colloidal particle results in the attraction of charge-compensating ions to the particle surface. These ions are distributed as a diffuse ion cloud, or double layer, surrounding the charged colloidal particle. An exact quantitative treatment of the double layer is a highly complicated problem due to the many factors involved, and as yet all of the answers to this problem have not been determined.³⁶ The mathematical distribution of the ions in a double layer is given by the Boltzmann distribution function and the Poisson equation, which must be solved simultaneously and at the same time must satisfy the boundary conditions of the system. For the simple case of the infinite plane, an exact solution of the Boltzmann-Poisson equation is presented by Mysels.³⁴ He further states that an exact solution of the Boltzmann-Poisson equations for the case of an infinite plane is justified when the ratio of the particle radius to the double layer thickness is ten or larger because the difference in curvature between the inner and outer portions of the double layer will be small.

Several models of the double layer have been

proposed.³³ However, the Stern model displays most of the properties of the double layer that have been inferred from experimental observations. The Stern model shows the counterions being composed of an adsorbed immobile surface layer plus a diffuse Gouy-Chapman layer extending into the bulk of the solution (see Fig. 2). The potential at the surface of the particle is designated ψ_0 , while the potential at the boundary between the Stern and Gouy-Chapman portions of the double layer is designated ψ_d . The only measurable potential in the double layer is the zeta, ζ , potential, which is the potential at the plane of shear separating the solvent bound to the colloidal particle from the bulk of the solution. The zeta potential is the only potential obtained by electrophoretic measurements.

Hydration

Due to the unique properties of water,³⁷ a charged colloidal particle changes the orientation of water dipoles in its electrical field. In such a "solvation shell," the degree of orientation of the dipoles will gradually decrease with increasing distance from the charged surface. Usually the layer of water which is tightly bound will have the thickness of a single molecule. However, some systems are

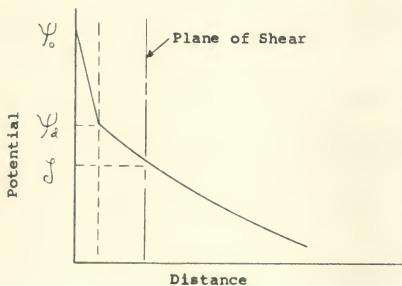
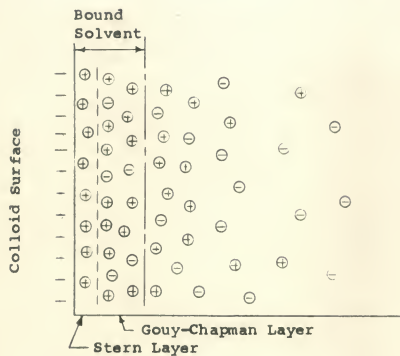


Fig. 2. Stern Model of the Electrical Double Layer (from Mysels³⁴).

encountered in which much larger amounts of water of hydration are present.³⁴ This water is held much less firmly and in fact may simply be trapped mechanically within the particles.

Gels are considered to be hydrated systems which hold water by trapping it mechanically. X-ray structural analysis and electron microscopy studies have shown that gels are composed of fibrous particles which are able to form a coherent meshwork and hold large amounts of liquid. The nature of forces and linkages responsible for the coherent structure of gels is not completely understood. It is generally accepted that in most gels the parts of the macromolecular or micellar framework must be linked either by a few primary bonds or many secondary valences. Primary bonds are involved in all gels of cross-linked polymers. However, in the gels of gelatin, pectin, nitrocellulose, and many other linear colloids, interlinking by primary bonds is improbable. For example, the gelatin gels may be liquefied by slight warming, and many gels of highly diluted linear colloids are thixotropic; i.e., they can be reversibly liquefied upon vigorous shaking. This indicates that primary valence forces are probably not present in such inter-linking. It is more likely that

hydrogen bonds and other types of residual valences are involved in the formation of the coherent structures. In the case of very asymmetric macromolecules of non-polar, linear colloids, mechanical entanglement of the molecules may also play some part in gel formation.³⁸ The concept of hydration and gel formation is important in sewage treatment, as it has been suggested that the large quantities of water held by sludge may be explained by hydration phenomena.

Stability and Instability of Colloidal Suspensions

As mentioned previously, the stability of a colloidal suspension is attributed to two phenomena. The main factor is believed to be the force of repulsion between the double layers of two surfaces of like charge. The secondary factor is hydration of the colloidal particles, which is explained by the mutual repulsion of the oppositely oriented water dipoles around colliding particles. There is some disagreement concerning the importance of hydration, and Van Olphen³³ indicates that this factor is only important when considering extremely short-range particle interaction, because the adsorbed water layer is only a few molecules thick.

The instability of a colloidal suspension is characterized by the coming together or agglomeration of the colloidal particles into larger particles which will settle from suspension. The principal forces which cause colloids to agglomerate can be broadly classified into coulombic and Van der Waal's forces. Coulombic forces are due to the net electrical charges of particles and may be attractive or repulsive; they decrease with the square of the distance, while Van der Waal's forces, although also based on electrical interactions, do not involve two net charges, are always attractive, and decrease more rapidly with distance.

The terms coagulation and flocculation have been used interchangeably by most research workers. La Mer,²² however, has made a distinction between the terms coagulation and flocculation in order to describe more accurately the basic mechanisms of polymer colloid interactions. Coagulation is defined as being a general kinetic process which obeys the simple Smoluchowski equation. It is brought about by neutralization of the repulsive potential of the electrical double layer, allowing the forces of attraction between particles to bring them together. Flocculation, on the other hand, is visualized as a completely different mechanism whereby colloidal particles are bound together

by a bridging mechanism, in which adsorption plays the major role.

Polymer Colloid Interaction

Investigations of the interactions of organic polyelectrolytes with colloidal suspensions have covered numerous polymer-colloid-solvent systems. Jenckel and Rumbach³⁹ were the first to propose the extended segment theory to explain observations that more polymer could be adsorbed on a surface than could be accounted for by a simple monolayer coverage. Similar conclusions were reached by other investigations.^{40,41,42,43} Simha, Frisch, and Eirich^{44,45,46} developed a theoretical model for polymer adsorption onto solid surfaces, but it is limited to monomolecular adsorption from dilute polymer solutions. In a more recent publication, Silberberg⁴⁷ presented general polymer adsorption equations for any strength polymer-surface interaction.

An interparticle bridging mechanism has been proposed by several investigators^{48,49,50} for the aggregation of particles with organic polyelectrolytes, while other investigators^{49,51,52} have proposed various mechanisms for the attachment of the polyelectrolytes to the colloidal particles.

La Mer, Smellie, and Kane^{10,11,12,13,14,15,16,17,18, 19,20} have investigated filtration and flocculation of silica suspensions and the flocculation, subsidence, and filtration of slurry suspensions of phosphate slimes. From their investigations they developed a mathematical theory for the polymer bridging mechanism which predicts maximum flocculation when one half of the particle surface is covered by the polymer molecules.

Molecular Weight and Coagulation-Flocculation

O'Driscoll⁵³ defines a polymer molecule as a number of repeating chemical units held together by covalent bonds. A compound is called a polymer if the repeating chemical units are of the same molecular species and a copolymer if the repeating chemical units are of more than one molecular species. The molecular weight of a polymer molecule is the sum of the molecular weights of the repeating units or monomers.

Polyelectrolytes are a special class of polymers which possess ionizable functional groups along the polymer chain. When a polyelectrolyte is dissolved in a solvent, the functional groups dissociate, causing the polymer molecule to become charged either positively or negatively,

depending on the specific functional groups present. Certain polyelectrolytes called polyampholytes possess both positively and negatively charged sites.

Kim⁹ investigated the effect of a threefold increase in the molecular weight of a cationic polymer on the removal of clay turbidity, but no significant difference could be detected. Birkner²⁴ investigated the effects of cationic polymer molecular weight on the destabilization of dilute clay suspensions and concluded there was no significant effect on the degree of suspension destabilization caused by polymers of different molecular weight, although the lower molecular weight polymer did exhibit a narrower zone of optimum turbidity removal. A similar observation was made by Warkentin and Miller⁵⁴ in their study of the effect of polymer chain length on the destabilization of slurry concentrations of montmorillonite clay with polyacrylic acid. An optimum polymer dosage was exhibited by both long- and short-chain polymers, but the short-chain polymer showed a narrower optimum dosage range. Priesing⁵⁵ indicates that the rate of coagulation-flocculation will be faster for polymers of higher molecular weight, since polyelectrolytes may be considered rods at infinite dilution and the higher the molecular weight the larger will be the

diameter within which the extended rods may colloid.

Flocculation and Settling of Activated Sludge

Activated Sludge Process

Biological removal and conversion of organic constituents in the conventional activated sludge process may be divided into two phases: (1) the organic waste is partially oxidized for free energy and partially synthesized into new microbial cells; (2) the flocculation and settling of newly synthesized cells is promoted by continued aeration in the same aeration tank. Settling must take place in the final clarifier because, without separation of the microorganisms from the liquid, only the portion of the organic matter that has been oxidized will be removed in the treatment plant. Therefore, a main factor in the over-all efficiency of a biological treatment process is flocculation and settling of the microbiota.⁵⁶

Experience has shown that when an activated sludge plant is operated with high organic loading rates and short aeration times the microorganisms tend to be non-flocculent and settle poorly. However, an activated sludge plant

operating at low organic loading rates and long aeration times provides conditions for excellent biological flocculation and settling.⁵⁷ Fig. 3 shows the relative tendency for the microbiota in an activated sludge process to remain dispersed with time of aeration.

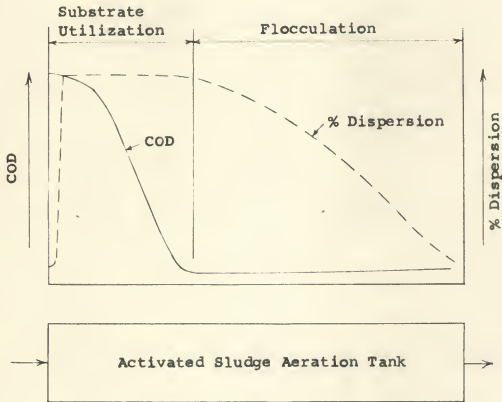


Fig. 3. Substrate Utilization and Flocculation in the Activated Sludge Process (from Tenney and Stumm⁵⁶).

Fig. 3 shows that longer aeration times are necessary for effective microbial flocculation and settling. This additional aeration represents a major portion of the total required and involves considerable expense to provide for liquid-solid separation. Various modifications of the activated sludge process have been utilized to compromise between the requirements of the substrate utilization phase and the bioflocculation phase. These modifications range from the "high rate" activated sludge process to the "extended aeration" activated sludge process. The "high rate" process provides a high loading rate and short aeration time resulting in optimal substrate utilization rates but poor bioflocculation and settling. The "extended aeration" process provides low loading rates and long aeration times, resulting in unfavorable conditions for substrate utilization but excellent conditions for bioflocculation and settling. None of the modifications, however, have been able to achieve a compromise without causing either a lower organic removal efficiency or excess cost for additional aeration.⁵⁸

Bioflocculation

Even today the mechanisms of bioflocculation are not clearly understood. The complexity of the bacterial surface compared with that of a hydrophobic inorganic colloid makes experimentation with bacteria extremely difficult. In 1939 Rudolf and Gehm⁵⁹ reviewed the various theories of colloidal adsorption in the aerobic treatment process proposed by Dunbar, Dienert, Theriault, Cavel, Buswell, Baly, and many others. Their investigations showed that the colloidal matter in sewage was adsorbed by the bacterial slimes, but they disagreed on the mechanisms involved. Theriault believed the gelatinous matrix of activated sludge to be a biozeolite substance and that organic materials were adsorbed onto the sludge by an ion exchange process. Electrical charge was the theory of Cavel and others. Cavel proposed a positively charged bacterial surface which adsorbed the negatively charged colloids in sewage. This idea was disproved by Buswell, who showed that both sewage colloids and bacteria were negatively charged. Baly and Lumb advanced the idea that the more negatively charged bacterial floc adsorbed the less negatively charged colloids.

Other than the work mentioned above, prior to 1939

little had been done to show how bacteria actually coalesce to form floc or how colloid adsorption occurred once the floc was formed. A coinvestigation by Rudolf and Gehm⁵⁹ in the late 1930's led to their proposal that a special floc-forming bacteria (e.g., Zooqloea ramigera) were primarily responsible for producing activated sludge floc. In addition, these authors hypothesized that protozoa aided flocculation by excreting a gelatinous slime to trap bacteria before ingestion. In 1952 McKinney and Harwood presented results of investigations they had made which disproved the theory of a special floc-forming bacteria. They isolated several organisms from activated sludge which were capable of forming floc, including Aerobacter aerogenes, Zooqloea ramigera, Bacillus cereus, and Escherichia intermedium. Microscopic examinations of the floc formed by the different bacteria showed little physical difference, therefore disproving the theory that a special zoogloea-producing bacteria was necessary for floc formation. It has since been realized that most microorganisms under proper conditions will tend to flocculate.^{60,61,62}

Bacteria and many other microorganisms are considered to be hydrophillic biocolloids. Understanding the dispersion stability of hydrophillic biocolloids is considerably

more difficult than other systems in that chemical conditions at the cell surface are changing constantly. Electrostatic repulsive forces do not fully explain the stability of bacterial suspensions, because it has been shown that charge reduction is not necessary in all cases for bio-flocculation.^{61,62} In fact, La Mer and Smellie^{10,15} have shown that negative colloidal dispersions can be effectively flocculated by negatively charged polyelectrolytes. The more important factor in the stability of microbial dispersions is probably hydration of the chemical substances found on the microbial surface.

In addition to factors mentioned above, the stability of bacterial dispersions is greatly affected by the physiological conditions of the cells. In aerobic waste treatment plants, microorganisms generally remain dispersed as long as they are growing prolifically (log growth phase). Conditions for bioflocculation improve in the declining growth phase and become optimal in the endogenous phase, especially after intense aeration (see Fig. 4). This would indicate that the microorganism's external surface changes its properties as the cell's physiological condition changes in going from active growth to endogenous respiration.⁵⁶

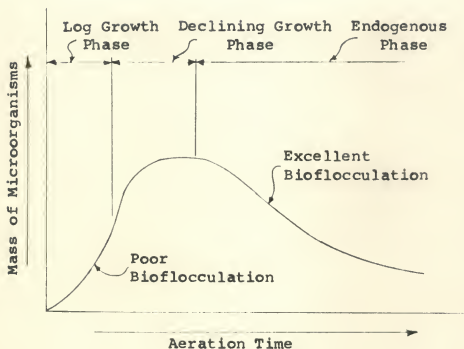


Fig. 4. Growth Pattern Based on Mass of Microorganisms.

McKinney⁶² noticed that as long as bacteria had energy enough they would not become part of a floc because they were capable of breaking away. It was only after the bacteria lacked sufficient energy that they became part of the floc. He summarized his findings by saying that there are many factors which affect biological flocculation, including energy content of the system, mass of active microorganisms, mass of inactive microorganisms, inorganic and organic colloids, salt concentration, agitation, and pH.

Of the previously mentioned factors, McKinney⁶² felt that the energy-microorganism relationship was the most important in floc formation.

The latest and most significant mechanism for bio-flocculation has been proposed by Tenney and Stumm.⁵⁶ Biological self-flocculation is interpreted in terms of inter-action of naturally produced polyelectrolytes which form bridges between individual microbial particles. They suggest that polymers of biological origin carrying electrical charges, such as proteins, protamines, nucleic acids, alginic acids, pectic acids, and numerous polyacids are of great importance in the organization of biological structure. Since natural polymers such as polysaccharides and polyamino acids are excreted or exposed at the surface predominantly during the declining growth and endogenous respiration phases, they propose that these polymeric molecules are of sufficient length to form connecting bridges among microbial particles. Tenney and Stumm⁵⁶ further indicate that chemical flocculation of microorganisms by synthetic polyelectrolytes may also be interpreted in terms of a polymer-bridge model.

Mode of Settling

Fitch⁶³ has divided sedimentation into four classifications depending upon the concentration of the suspension and the flocculating tendency of the particles. These classifications are discrete settling, flocculent settling, zone settling, and compression. Discrete settling describes a system of individual particle maintenance during a settling process. Flocculent settling is characterized by particle agglomeration, which results in a changing settling rate. During compression the floc concentration is so great that the upper layers receive mechanical support from those below.⁶⁴

Zone settling, sometimes called hindered settling or free sludge settling, relates to particles which are locked into a floc structure. The flocculated particulates descend through the suspending liquid at a constant rate without pressing on layers of floc below. Activated sludge is an excellent example of zone settling, as all particles are constrained to settle at the same rate.

The settling rate of a given sludge is governed, among other things, by concentration of suspended solids. The quantity of solids which can pass down through any layer of liquid is equal to the product of the settling

rate, concentration of suspended solids, and the cross-sectional area. Therefore, the maximum solids quantity which can pass through a given stratum is governed by the solids concentration.⁶³

In Appendix B a method is derived for designing activated sludge settling tanks, taking into consideration the area required for both clarification and solids handling. This method is based on batch settling tests as used in the present investigation and is useful in comparing different activated sludge settling rates and their effects on the design of activated sludge clarifiers.

Sludge Dewatering by Vacuum Filtration

General

Sludge is composed of settleable solids naturally present in waste water and the non-settleable matter that is removed from waste water by chemical coagulation and precipitation or biological flocculation and precipitation. Sludges are loose structures of particulate and flocculent material containing large volumes of water. Since sludge contains bacteria, virus particles, and certain helminth ova, all of which are potential pathogens to man, proper disposal is paramount. In addition, the aesthetic and

economic considerations of sludge disposal are great. Sludge production, treatment, and disposal compose a large percentage of the initial and operating cost of a municipal sewage treatment plant because thousands of gallons of putrescible and potentially dangerous sludge are removed from each million gallons of sewage treated. Due to the large volumes of sludge and high percentage of water, sludge dewatering is a major process in sewage treatment.

Vacuum Filtration

Filtration is a unit operation for separating solids from liquids and may be performed by four different means: (1) gravity, (2) pressure, (3) vacuum, and (4) centrifugal force. Of these, gravity and vacuum filtration are the most common. Gravity filtration finds its widest application in the dewatering of anaerobically digested sludge on sand beds. However, because sand beds require a fairly large area of land, the use of vacuum filters is common where land areas are limited and weather conditions are not favorable for sand filters.

Vacuum filtration commonly is carried out on slowly rotating drum filters in a continuous operation. For a discussion of methods and equipment used in vacuum filtration,

the reader is referred to other texts.^{1,35,64} The rate of vacuum filtration depends on many variables, including amount of vacuum, amount of solids in the sludge, and nature and condition of the sludge. Fresh raw sewage sludge is relatively easy to filter, while the most difficult sludge to filter is from the activated sludge process.

To increase filter rates, chemical conditioning of the sludge is commonly practiced. Common conditioning chemicals for sewage sludge are ferric chloride, chlorinated copperas, ferric sulfate, aluminum sulfate, and lime. By far the most widely used chemicals are a combination of ferric chloride and lime. However, in recent years synthetic polymers are finding greater application in this field.

Little is known about the basic mechanisms of chemical conditioning for sludge dewatering. Genter^{65,66} showed that both the solid and liquid portions of a sewage sludge have a demand for inorganic chemicals. The solids demand is related to the volatile content of the sludge and the liquid demand to the bicarbonate alkalinity of the sludge liquid. He found that by diluting the sludge with a water of low alkalinity, thickening the washed solids, and decantation of the supernatant a large reduction in the chemical demand could be achieved. This process is called

sludge elutriation. Dahlstrom and Cornell⁶⁷ found that the amount of agitation when chemicals were mixed with sludge had a pronounced effect on the rate of vacuum filtration. Similar effects were found by Healy and La Mer¹⁶ in work on the refiltration rates of calcium phosphate suspensions. They noted that maximum filtration rates depended on time of agitation, and lower filtration rates were observed when agitation time was above or below the optimum.

Kane, La Mer, and Linford⁶⁸ found the cationic polymers capable of changing the electrophoretic mobilities of silica suspensions from negative to positive. They further observed that the maximum refiltration rates were produced when the electrophoretic mobility of the suspension had been reduced to approximately $0.0 \mu/\text{sec}/\text{v}/\text{cm}$. Similar results were found by Oakes and Burcik⁶⁹ in studies on Wyoming bentonite clay.

In an earlier article Healy and La Mer¹⁶ investigated the effect of the molecular weight of polyacrylamide on the refiltration rates of calcium phosphate suspensions. They found that a molecular weight of approximately $3(10)^6$ produced the maximum refiltration rates, while molecular weights above or below that value produce refiltration rates of lower values. There may be some question as to whether

the results of La Mer et al. may apply to the filtration of sewage sludge. La Mer was experimenting with dilute concentrations (less than 1,000 mg/l) of inorganic materials such as calcium phosphate and silica. While in the vacuum, filtration of sewage sludge concentrations of 50,000 mg/l and 60 percent organic matter are not uncommon.

Vacuum filtration is essentially a special case of liquid flow through a bed of solids. Chemical conditioning results in the flocculation of small particles by charge neutralization and inter-particle bridging to form loose, porous aggregates that lead to an increased liquid flow. The filtration process can be formulated for conditions of streamline flow by the application of Poiseuille's and D'Arcey's laws. This formulation was developed by Carman^{70,71} and extended by Coackley.^{72, 73} Carman introduced the idea of specific resistance (resistance per cc of cake) and Coackley introduced a method of determining the filterability of sludge based on determining the specific resistance from a laboratory scale filtration test. Jones⁷⁴ has derived formulas for determining vacuum filter yields based on specific resistance determinations. See Appendix C for a sample calculation of the specific resistance of an anaerobically digested sludge based on results from a laboratory filtration test.

III. EXPERIMENTAL MATERIALS AND PROCEDURES

Materials

Domestic Waste Samples

Coagulation-flocculation experiments on raw and settled sewage were conducted on grab samples from the University of Florida and the Gainesville sewage treatment plants. In a like manner, experiments on the settling rates of activated sludge were conducted on grab samples from the University of Florida and Daytona Beach, Florida, sewage treatment plants. For the final series of tests on vacuum filtration of digested sludge, grab samples were taken from the anaerobic digestors of the University of Florida sewage treatment plant.

Industrial Waste Samples

Coagulation-flocculation experiments were conducted on a 24-hour composite sample of the waste water from Koppers Company, Inc., Forest Products Division Plant, Gainesville, Florida. This plant is involved in pressure treating of lumber, fence posts, telephone poles, etc.,

with creosote and other preserving chemicals. The waste water contains considerable quantities of both dissolved and suspended chemicals, the suspended matter being in the form of an oil emulsion.

The second industrial waste used in coagulation-flocculation experiments was from the Glidden Organic Chemical Company, Jacksonville, Florida. This industrial plant is involved in the production of a variety of organic chemicals from pulp and paper mill waste products. The effluent from this plant contains large quantities of dissolved and suspended organic chemicals which are lost into their waste water stream from various batch processes.

Chemical analysis of each raw waste is included in the tabulated results from all laboratory experiments.

Organic Polyelectrolytes

The three Cat Floc* cationic polymers used in this investigation, which were designated Cat Floc No. 1, Cat Floc No. 2, and Cat Floc No. 3, have intrinsic viscosities of 2.40, 5.95, and 6.75 deciliters/gram respectively. Cat Floc is a linear homopolymer of diallyldimethylammonium

*A product of Peninsular Chemresearch, Inc., Gainesville, Florida.

chloride consisting of a linear chain of recurring N-substituted piperidinium halide units alternating along the chain with methylene groups. The ionized form of this cationic polymer is shown in Fig. 5.

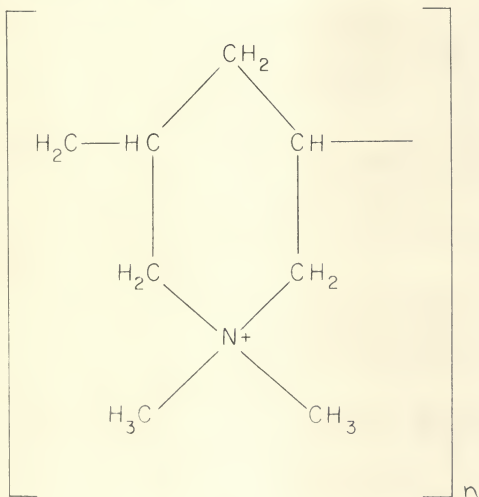


Fig. 5. Ionized Form of Cat Floc.

An empirical relation between intrinsic viscosity and molecular weight, $[\eta] = KM^\gamma$, has been found to be applicable to a large number of polymer solvent systems.³⁹ In the above equation $[\eta]$ is the intrinsic viscosity, K is a constant, γ is a constant, and M is the "viscosity-average molecular weight," since all of the solute molecules are not of the same molecular weight. Values of K and γ depend on many variables, including type of polymer, solvent, structure of the polymer, heterogeneity of the sample, and temperature. Tabulations of K and γ have been published^{75,76} for various polymer solvent systems; however, these tabulations are only useful as rough guides. To determine the relationship between viscosity measurements and molecular weights for any polymer system, it is necessary to determine experimentally the values of K and γ . This must be done by measuring the viscosity of polymer samples, then determining their molecular weights by osmotic pressure, light-scattering, or some other means. Once the viscosity and molecular weights of several samples are known, the values of K and γ may easily be computed.

Only a minimum of data was available for the samples of Cat Floc used. However, using the available data and assuming that the polymer molecules are extended and rodlike

giving a γ value of 2,⁷⁶ the molecular weights of the three Cat Floc samples were computed. The calculated relative molecular weights of the three Cat Floc samples are: Cat Floc No. 1, a relative molecular weight of 1.00; Cat Floc No. 2, a relative molecular weight of 1.57; and Cat Floc No. 3, a relative molecular weight of 1.72. The calculated average molecular weight of Cat Floc No. 3 was less than $30(10)^4$. All three Cat Floc samples were cationic.

The Purifloc C-31* polyelectrolyte used in this investigation was a polyamine of high molecular weight and when ionized was cationic. The designation given to this polymer was Dow C-31. No data are available concerning the molecular weight of the sample used in this investigation. The Dow Chemical Company lot number was 713445.

The Primaflow C-7** polymer used in this investigation was also a cationic polyamine of high molecular weight. This polymer had a molecular weight over $1(10)^6$. The Rohm and Haas lot number was 0808.

*A product of the Dow Chemical Company, Midland, Michigan.

**A product of the Rohm and Haas Company, Philadelphia, Pennsylvania.

Procedures

Preparation of Organic Polyelectrolytes

Cat Floc sample No. 1 was received as a water solution containing 17.7 percent polymer. Cat Floc sample No. 2 was received as a water solution containing 14.8 percent polymer and Cat Floc sample No. 3 was received as a water solution containing 5.2 percent polymer. Working solutions were prepared by diluting with deionized water until solutions of $(10)^1$, $(10)^0$, $(10)^{-1}$ mg/ml were obtained.

The Dow C-31 sample was received in liquid form, and for stock solution purposes was assumed to be 100 percent polymer. Working solutions were prepared by dilution with deionized water until solutions of $(10)^1$, $(10)^0$, $(10)^{-1}$ mg/l were obtained.

The Primaflor C-7 was received as a water solution containing 2.0 percent polymer. Working solutions were prepared in the same manner as for the other polymers by dilution with deionized water until solutions of $(10)^1$, $(10)^0$, $(10)^{-1}$ mg/l were obtained.

Jar Test Procedure

Four multiple laboratory stirrers* permitting the

*Manufactured by Phipps and Bird, Richmond, Virginia.

simultaneous mixing of 24 one-liter samples were used throughout the investigation. The tachometers indicating mixing rate were calibrated with a stop watch. The sample jars were supported on translucent bases permitting light to pass upward through the samples, making it possible to observe the relative time of floc growth and also floc size and settling rate. Coagulant dosages to be used in each jar were prepared in advance by adding the desired amount of polymer to a small glass beaker and diluting to 25 ml with demineralized water. This made it possible to dose all 24 jars in a relatively short period of time.

Time and rate of mixing depended on the over-all objective of the experiment. When experiments were conducted to determine the over-all efficiency of the polymers, the samples were mixed at 100 rpm for 20 minutes, followed by a 20-minute flocculation period at 20 rpm. When the effect of revolutions of mixing was the objective, a constant rate of either 20 or 80 rpm was employed. For all jar tests, samples were allowed to settle for 15 minutes.

Within three minutes after the addition of the polymer to a sample jar, a 75 ml sample was removed for the electrophoretic mobility determination. At the end of the settling period, a 250 ml sample was withdrawn from the

supernatant in each jar by means of a suction apparatus connected to a vacuum source and ending in a U-bent tube so as to permit sampling at a uniform depth of 1-1/2 inches below the surface of the liquid in the jar. Part of the sample was used for determining the final pH and residual suspended solids, and another portion, for the BOD determination. All the determinations were made as soon as possible after sampling.

Solids Determinations

In previous work, the Standard Methods Gooch crucible procedure⁷⁷ for the determination of suspended solids had been used with poor results. Therefore, it was decided that another method would be used. The difficulties with the Standard Methods Gooch crucible procedure have been summarized by various authors^{78,79,80} as being due to preparation of non-uniform asbestos mats, variation in asbestos quality, mat disturbance during handling, and slow rate of filtration. For these reasons and experience in the past, suspended solids were determined, using glass fiber filters. The use of glass fiber filters for solids determinations has been discussed by several authors, and they have shown that glass fiber filters give accurate results and are easy to use.

Gooch crucibles containing 2.4cm glass fiber filters cut from glass fiber sheets* were prepared by filtering 100 ml demineralized water through the filter, drying at 103° C for one hour, cooling in a desiccator, then weighing on an automatic balance.** To determine suspended solids, 50 ml samples were filtered, the Gooch crucibles and filters were dried at 103° C, cooled, and again weighed. For each series of experiments in which suspended solids were determined, a series of blanks was also included to take into account any variability that might otherwise have gone unnoticed.

Solids content of activated and digested sludge was determined by filtering a 200 ml sample through a previously dried and weighed 15 cm Watman No.1 filter paper, which was supported in an 11 cm Buchner funnel. Placing a 15 cm filter paper in an 11 cm Buchner funnel prevented the loss of solids around the edge of the filter, which is a common problem in this type of determination.

Electrophoretic Mobilities

Electrophoretic mobilities were determined by means

*Product of Mine Safety Appliance Company, St. Louis, Missouri.

**Product of August Sauter of New York, Inc., Albertson, New York.

of a Zeta-Meter.* The ocular micrometer grid in the microscope eyepiece was calibrated⁸¹ against a micrometer subdivided to 0.01 mm and found to be in agreement with the values given in the Zeta-Meter Manual⁸² for the three objective magnifications available, when measured along the counting lines between vertical grid divisions. The distances between the counting lines and the "zero line" were also calibrated with the micrometer and found to be correct for a 4 mm diameter cell, since they correspond to 0.147 of this diameter times each total magnification of the microscope. This factor agrees with the position of the stationary layer in a cylindrical cell as given by Kruyt.⁸³

For each sample, between five and ten particles were timed in each direction, using the timer in the instrument. All observations were made at 133 volts, as any higher voltage caused thermal overturn or gassing of the electrodes due to the high ionic strength of the samples. The calculated mobilities are time-averaged rather than velocity-averaged mobilities.

Electrophoretic mobility values are recorded only for the coagulation-flocculation experiments on raw sewage

*An instrument made by Zeta-Meter, Inc., New York, New York.

and industrial wastes. Initially an attempt was made to determine the electrophoretic mobility of the samples of activated sludge used in the settling rate experiments. However, due to the large size of the floc particles and their rapid settling rate, only qualitative results could be obtained and the attempt was abandoned.

Measurement of pH

All pH measurements were made with a Beckman Model G pH Meter.*

BOD Determinations

BOD determinations were made in accordance with Standard Methods,⁷⁷ and three dilutions for each sample were used.

Sludge Settling Rate Procedure

Settling rates of activated sludge were determined by measuring the height of the interface between the sludge and supernatant over a period of time while a sample was settling in a special tube. Four plexiglass tubes were utilized, each 30 inches high and 6 inches in diameter. The

*Manufactured by Beckman Instruments, Inc., Fullerton, California.

large size of these tubes kept the side wall effect to a minimum and provided reproducible results. In order that the settling tests could be conducted as soon as possible after the samples were taken, the settling tests were conducted beside the aeration basins at the sewage treatment plants. In all cases, settling tests were begun within five minutes after the samples were taken from the aeration basins.

Each settling tube was filled to a depth of 27 inches with activated sludge, and the desired amount of polymer was diluted to 200 ml with distilled water, then added to the tube. After each tube was inverted four times, the elapsed time and height of the interface between the sludge and supernatant were recorded at intervals for a period up to 40 minutes.

Buchner Funnel Vacuum Filtration Test

In one experiment, vacuum filtration characteristics of a sludge sample were determined in terms of specific resistance by the Buchner funnel test. The procedure for conducting the Buchner funnel tests was adapted from Eckenfelder⁶⁴ and Parsons.¹ An 11 cm Whatman No. 4 filter paper was moistened, placed in a Buchner funnel, and a vacuum was

applied. A sample was prepared by adding the desired amount of polymer diluted to 50 ml with distilled water to 200 ml of sludge. The sludge was then mixed with polymer by inverting four times in a 250 ml graduated cylinder. The vacuum was turned off and the sludge was poured into the funnel. After approximately five seconds had passed to allow cake to form 20 inches Hg vacuum was applied to the filter. The volume of filtrate passing through the filter was measured during certain intervals of time by catching the filtrate in a 250 ml graduate cylinder provided for this purpose. The specific resistance was then calculated from the data obtained by a method given in Appendix C.

Filter Leaf Vacuum Filtration Test

Vacuum filtration characteristics of sludge may also be determined by the filter leaf test. According to several authors,^{1,67} the filter leaf test is better suited for design purposes than the Buchner funnel method because, in the filter leaf test, both thickness and filtration rate are a function of the effectiveness of the chemical treatment, since the sludge is picked up by the vacuum. The filter leaf procedure used was adapted from methods described by Parsons¹ and Eckenfelder.⁶⁴

A 0.1 square foot filter leaf with a polypropylene POPR-873* filter medium was used for the filtration tests. The desired amount of polymer diluted to 25 ml was added to one liter of sludge. The sample was then mixed in a large plastic container by stirring at 100 rpm for 30 seconds with a multiple laboratory stirrer. The desired vacuum was applied to the filter leaf, and the leaf was immersed in the sample for 1-1/2 minutes. The sample was mildly agitated throughout the test. The filter leaf was then moved slowly out of the sample and held in a vertical position for 3-1/2 minutes while the cake dried. The vacuum was removed from the filter, and the cake was removed, weighed, and the moisture content of the cake was determined by oven drying at 103° C and reweighing. The filter production was expressed as grams/ft² dry solids.

*A product of the Eimco Corporation, Salt Lake City, Utah.

IV. PURPOSE AND SCOPE

This study was designed to evaluate the effectiveness of a synthetic cationic organic polymer for the coagulation-flocculation of domestic waste water and two industrial waste waters. Variables studied included the effect of polymer molecular weight, effect of rate and time mixing, effect of addition of hydrated lime for pH variation, character and settling rate of floc, reduction in BOD and suspended solids, and effect of polymer dosage on the electrophoretic mobility of floc particles. The polymer of primary concern, Cat Flocc, was also compared with two other synthetic cationic organic polymers for coagulation-flocculation of domestic waste water.

In addition, studies were made of the effect of polymer molecular weight on the rate of settling of activated sludge from two sewage treatment plants and on the vacuum filtration of anaerobically digested sludge.

V. EXPERIMENTAL RESULTS

Coagulation-Flocculation

Figs. 6 to 8 show the results obtained in the coagulation-flocculation of sewage from the effluent of a University of Florida primary settling tank with Cat Floc polymers Nos. 1, 2, and 3. In these figures residual BOD, residual suspended solids, and electrophoretic mobility are plotted against polymer dosage for each Cat Floc polymer. Throughout this discussion it should be kept in mind that Cat Floc Nos. 1, 2, and 3 are the low, medium, and high molecular weight polymers respectively.

The electrophoretic mobility values of colloidal particles in all raw sewage samples were found to be in the range of -1.7 to -1.8 $\mu/\text{sec}/\text{v}/\text{cm}$. These values are in accordance with published electromobility values for domestic waste water found by Faust and Manger.⁸⁴ The figures show that increasing the dosage of Cat Floc changed the mobilities from negative to positive and, with further increases in dosage, the mobilities approached a limiting positive value probably because the surface area of the

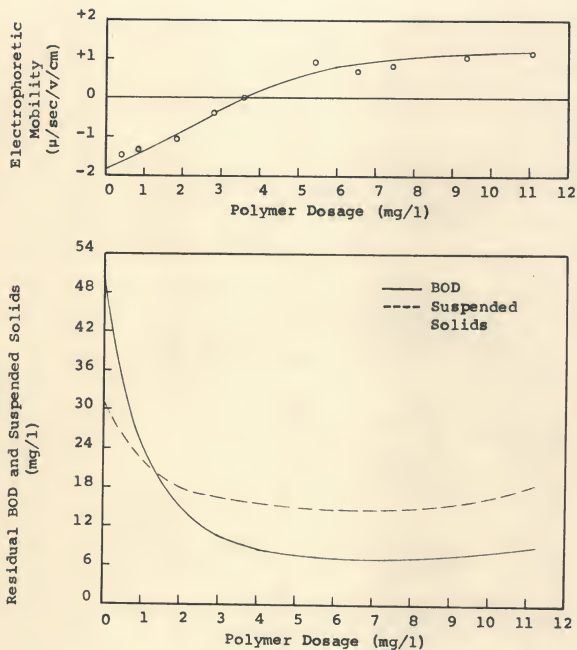


Fig. 6. Effect of Various Dosages of Cat Floc No. 1 on Removal of BOD and Suspended Solids in Sewage from the Effluent of a University of Florida Primary Settling Tank.

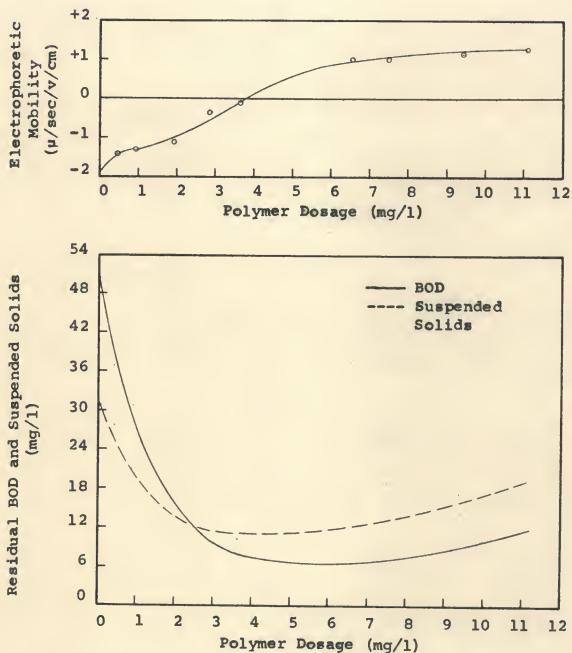


Fig. 7. Effect of Various Dosages of Cat Floc No. 2 on Removal of BOD and Suspended Solids in Sewage from the Effluent of a University of Florida Primary Settling Tank.

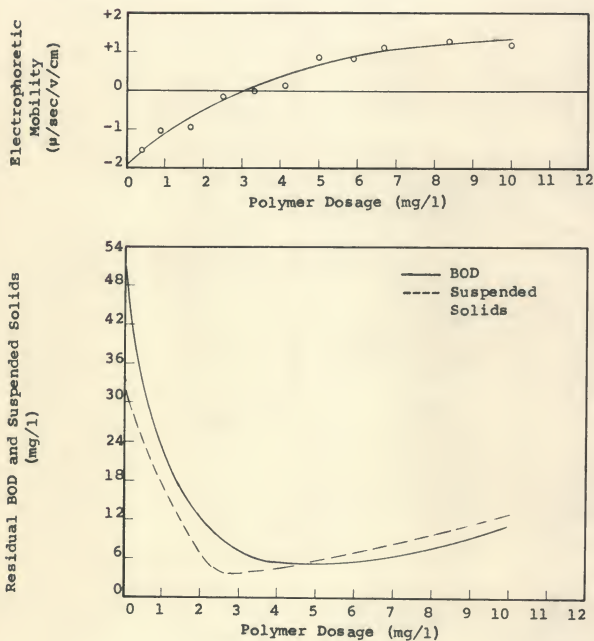


Fig. 8. Effect of Various Dosages of Cat Floc No. 3 on Removal of BOD and Suspended Solids in Sewage from the Effluent of a University of Florida Primary Settling Tank.

colloids was becoming saturated with polymer. BOD values for the settled sewage were lowered from an initial 50 mg/l to approximately 7 mg/l by each of the three Cat Floc samples, and values for suspended solids were lowered from 31 mg/l to a range of from 5 to 10 mg/l for all three polymers. Although the grab sample used in this test was a weak domestic sewage, it is remarkable that the BOD could be lowered to 7 mg/l simply by coagulation-flocculation. This indicates that most of the BOD present was in the form of suspended matter and little was in the dissolved state. A comparison of the mobility values in Figs. 6 to 8 shows virtually no difference in the change in electrophoretic mobilities with dosage. A comparison of values for BOD and suspended solids removal also showed little difference in the over-all efficiencies, and any small differences are within the analytical errors of the determinations. It should be noted that good BOD and suspended solids removal varied over a wide range of electrophoretic mobilities, and only after mobility values became exceedingly positive did the residual BOD and suspended solids tend to increase.

Figs. 9 to 11 show the results of coagulation-flocculation experiments on sewage from the effluent of a Gainesville primary settling tank. The BOD and suspended

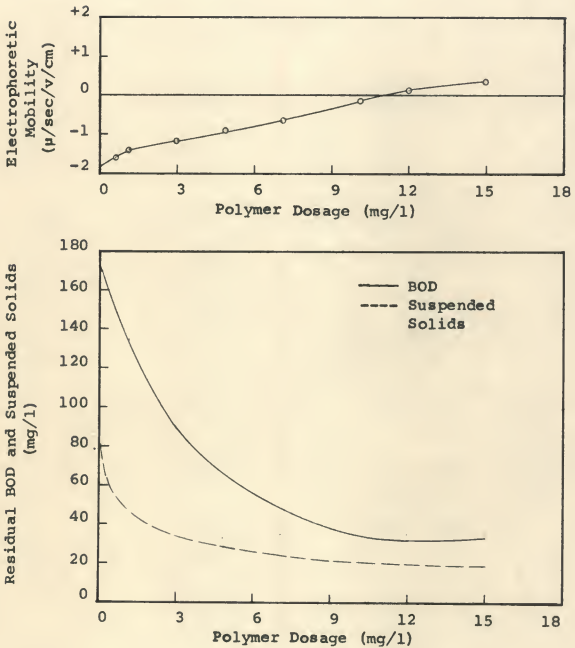


Fig. 9. Effect of Various Dosages of Cat Floc No. 1 on Removal of BOD and Suspended Solids in Sewage from the Effluent of a Gainesville Primary Settling Tank.

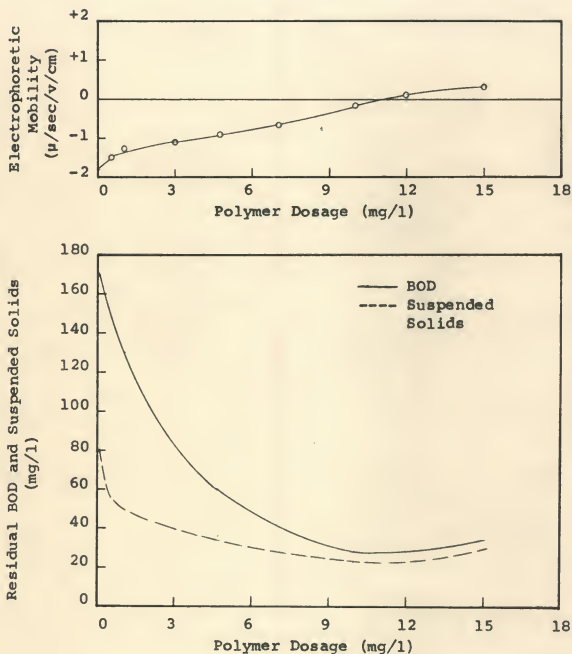


Fig. 10. Effect of Various Dosages of Cat Floc No. 2 on Removal of BOD and Suspended Solids in Sewage from the Effluent of a Gainesville Primary Settling Tank.

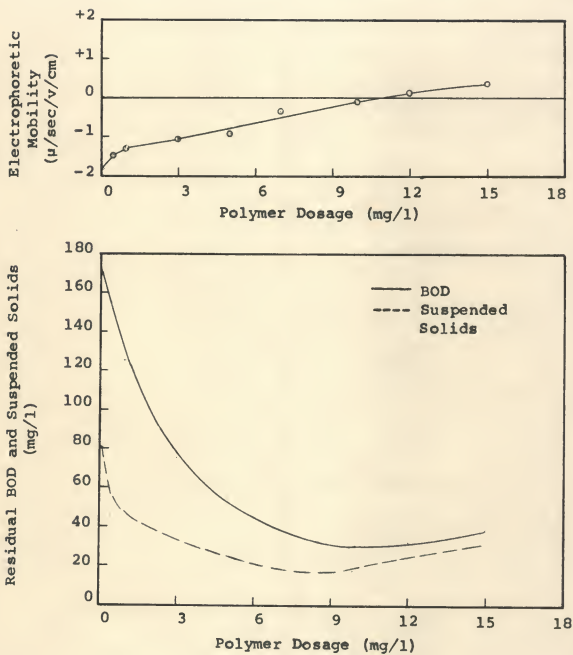


Fig. 11. Effect of Various Dosages of Cat Floc No. 3 on Removal of BOD and Suspended Solids in Sewage from the Effluent of a Gainesville Primary Settling Tank.

solids were considerably higher than that of the settled sewage from the University of Florida treatment plant, and because of this a higher polymer dosage was required to change the electrophoretic mobilities and lower the BOD and suspended solids. BOD values were reduced from 170 mg/l to approximately 30 mg/l, and suspended solids were reduced from 80 mg/l to approximately 20 mg/l by all three polymer samples. Electrophoretic mobilities were changed from -1.8 to +0.3 μ /sec/v/cm, only because enough polymer was not added to change the electrophoretic mobilities to more positive values. One way to determine the required polymer dosage range for jar tests on domestic wastes is to add varying quantities of polymer to the waste and determine the change in electrophoretic mobility. Domestic waste varies widely in composition from minute to minute; therefore, the optimum polymer dosage will vary widely also. A comparison of Figs. 9 to 11 shows little or no effect on charge in electrophoretic mobility or reduction of BOD and suspended solids due to the difference in molecular weight of Cat Floc Nos. 1, 2, and 3. It should be noted that the BOD reduction from 170 mg/l to 30 mg/l was due to the removal of colloidal matter, as it is assumed that Cat Floc does not remove any dissolved organic matter. This

indicates that a large portion of the BOD in sewage is in the colloidal form and may be easily removed by coagulation-flocculation with Cat Flocc.

Figs. 12 to 14 show the results of coagulation-flocculation experiments on sewage from the effluent of the Gainesville grit chamber. In the previous figures, results have been given on the coagulation-flocculation of settled sewage to show how much of the BOD in sewage that is not removed by sedimentation may be removed by coagulation-flocculation with a cationic polymer. In actual practice, however, coagulation-flocculation would be conducted on unsettled sewage and Figs. 12 to 14 show the results that may be expected when using Cat Flocc. A very sharp drop in BOD from 152 mg/l to 60 mg/l was achieved with 0.5 mg/l polymer dose even though the electrophoretic mobility was changed only from -1.7 to -1.4 μ /sec/v/cm. A portion of this BOD removal may be attributed to suspended solids that are readily settleable; however, a 60 percent reduction in BOD could not be achieved simply by settling for 15 minutes. This removal of BOD is primarily due to interparticle bridging of the larger colloidal matter and not to a reduction of electrophoretic mobility. Throughout the experiments on unsettled sewage, it was visually noticed that

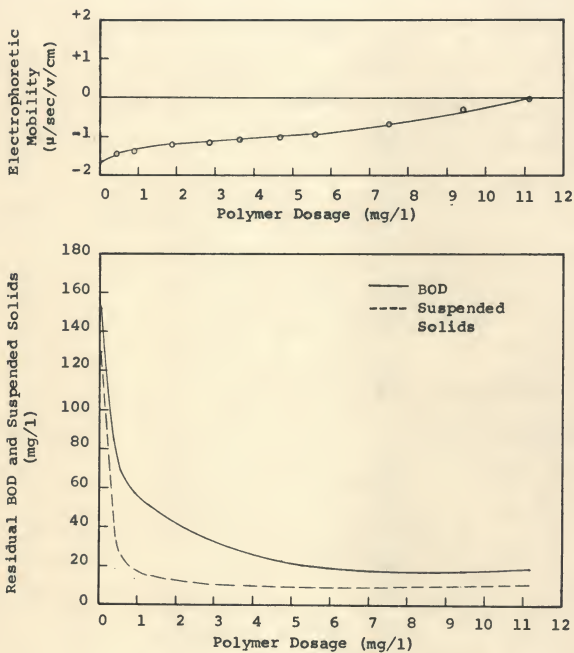


Fig. 12. Effect of Various Dosages of Cat Floc No. 1 on Removal of BOD and Suspended Solids in Sewage from the Effluent of the Gainesville Grit Chamber.

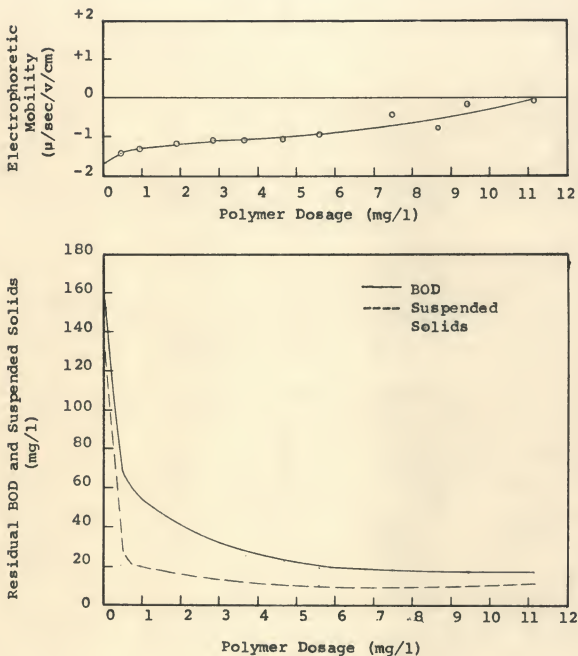


Fig. 13. Effect of Various Dosages of Cat Floc No. 2 on Removal of BOD and Suspended Solids in Sewage from the Effluent of the Gainesville Grit Chamber.

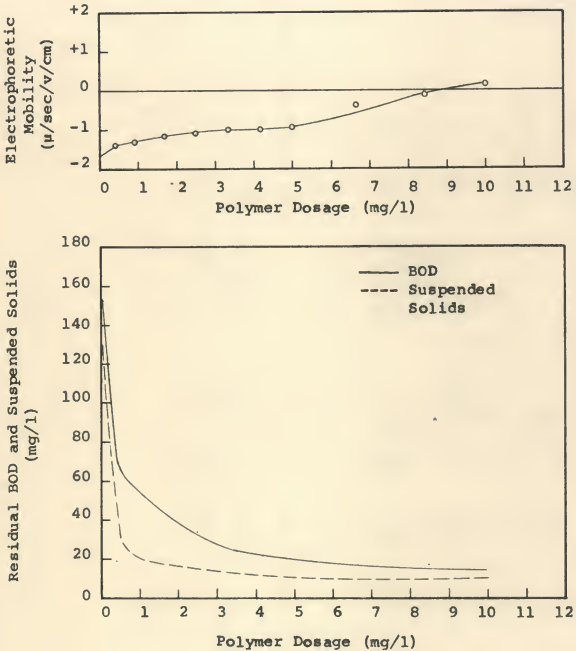


Fig. 14. Effect of Various Dosages of Cat Floc No. 3 on Removal of BOD and Suspended Solids in Sewage from the Effluent of the Gainesville Grit Chamber.

low dosages of Cat Floc were capable of causing the larger suspended material to form floc and settle rapidly. It was also noticed that the higher molecular weight Cat Floc sample consistently formed larger floc which settled more rapidly than Cat Floc Nos. 1 and 2. In Figs. 12 to 14 suspended solids were reduced from 130 mg/l to 20 mg/l with 0.5 mg/l of polymer, and further increases in polymer dosage reduced the suspended solids down to 10 mg/l and the BOD down to 18 mg/l. This represents a BOD reduction of 88 percent and a suspended solids reduction of 95 percent. The expression of treatment efficiency in percentages is often misleading as percentage of reduction will vary widely, depending on the initial concentration even though the final results may be the same. Almost any sewage treatment plant operator would be more than happy to continually put out an effluent with a BOD of 18 mg/l and suspended solids of 10 mg/l. A comparison of Figs. 12 to 14 indicated little difference in coagulation-flocculation caused by differences in molecular weight of the three Cat Floc samples.

The effect of various dosages of Cat Floc Nos. 1, 2, and 3 on coagulation-flocculation of sewage from the effluent of the University of Florida grit chamber are shown in Figs. 15 to 17. Polymer dosages were high enough to change the

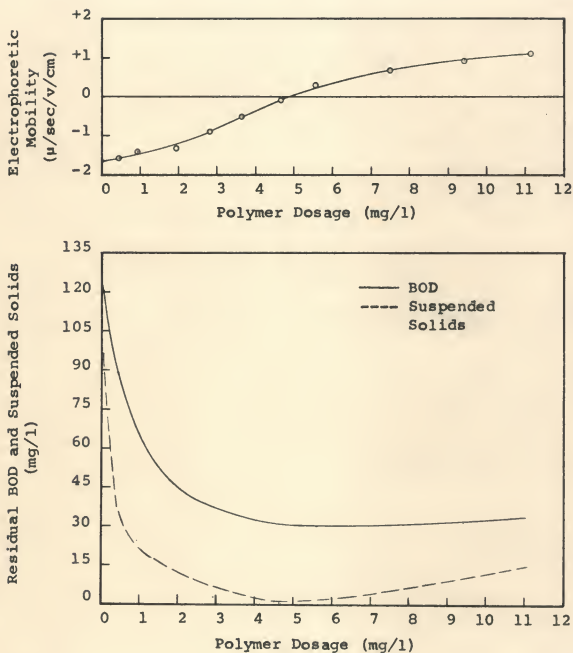


Fig. 15. Effect of Various Dosages of Cat Floc No. 1 on Removal of BOD and Suspended Solids in Sewage from the Effluent of the University of Florida Grit Chamber.

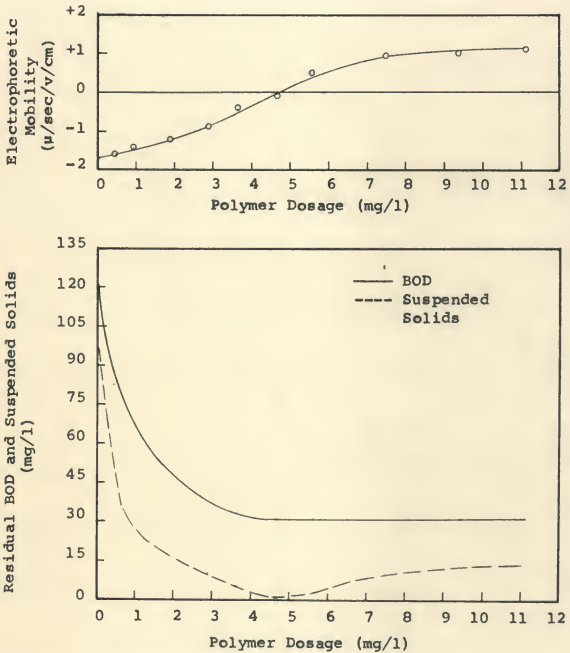


Fig. 16. Effect of Various Dosages of Cat Floc No. 2 on Removal of BOD and Suspended Solids in Sewage from the Effluent of the University of Florida Grit Chamber.

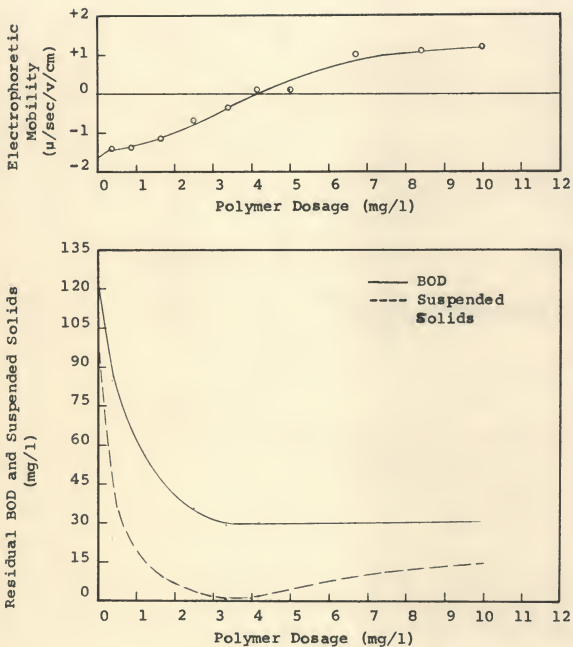


Fig. 17. Effect of Various Dosages of Cat Floc No. 3 on Removal of BOD and Suspended Solids in Sewage from the Effluent of the University of Florida Grit Chamber.

electrophoretic mobilities from -1.7 to $+1.2$ $\mu/\text{sec}/\text{v}/\text{cm}$. BOD values decreased with increasing polymer dosages until a minimum BOD value was achieved at a mobility of approximately 0.0 $\mu/\text{sec}/\text{v}/\text{cm}$. There is little difference, however, in the suspended solids reduction efficiency in a wide range of mobility values from -0.3 to $+1.2$ $\mu/\text{sec}/\text{v}/\text{cm}$. BOD values were reduced from 120 mg/l to 30 mg/l , while the suspended solids were reduced from 95 mg/l to 0 mg/l ; at the optimum polymer dosage the Cat Floc samples removed all of the colloidal material, leaving a crystal clear supernatant, the residual BOD being due to the remaining dissolved organic matter. Again, little difference caused by the variation in molecular weights of the three Cat Floc samples can be noticed from Figs. 15 to 17.

Figs. 18 to 20 show the results of coagulation-flocculation of sewage from the effluent of the University of Florida grit chamber with Cat Floc No. 3, Dow C-31, and Primafloc C-7. The Cat Floc No. 3 dosage required to change the electrophoretic mobility from -1.7 to 0.0 $\mu/\text{sec}/\text{v}/\text{cm}$ was approximately 5.5 mg/l , while 28 mg/l of Dow C-31 and 22 mg/l of Primafloc C-7 were required to achieve zero mobility. All three polymers showed the same ability to remove suspended solids and showed essentially the same

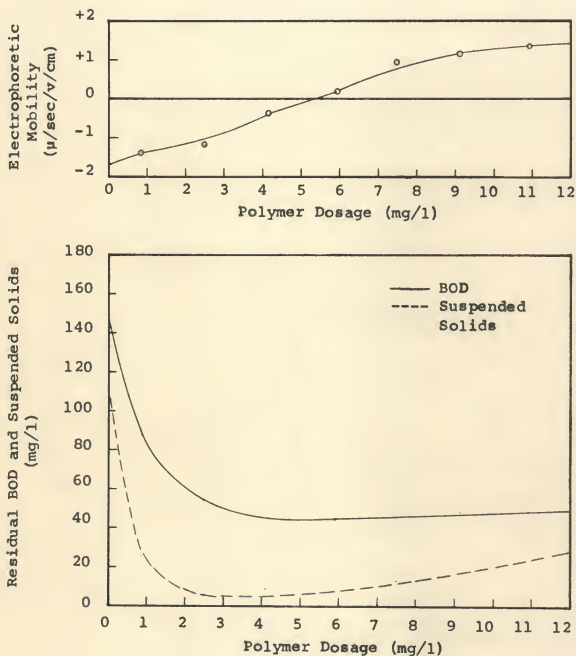


Fig. 18. Effect of Various Dosages of Cat Floc No. 3 on Removal of BOD and Suspended Solids in Sewage from the Effluent of the University of Florida Grit Chamber.

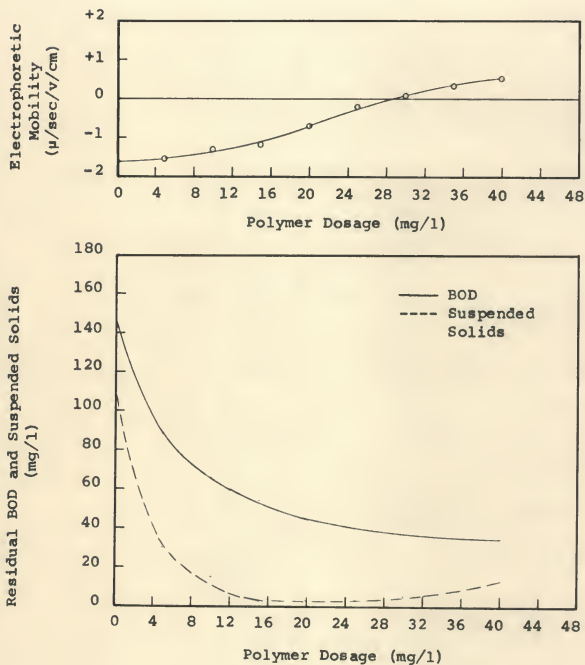


Fig. 19. Effect of Various Dosages of Dow C-31 on Removal of BOD and Suspended Solids in Sewage from the Effluent of the University of Florida Grit Chamber.

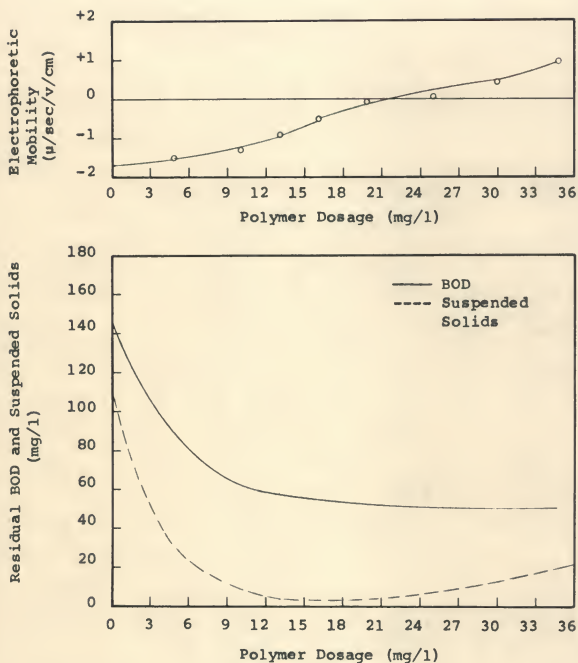


Fig. 20. Effect of Various Dosages of Primaflor C-7 on Removal of BOD and Suspended Solids in Sewage from the Effluent of the University of Florida Grit Chamber.

optimum range of electrophoretic mobility for suspended solids reduction. An increase in dosage of the three polymers beyond the optimum resulted in a dispersing effect and an increase in the residual suspended solids. At the optimum dose range for removal of suspended solids, BOD removal was very nearly the same for the three polymers. However, with increasing polymer dosages, there was a difference in the BOD removal by the three polymers. As the polymer dosages increased, the residual BOD for the Cat Floc No. 3 polymer increased, while for the Dow C-31 polymer the BOD decreased slowly and for the Primaflor C-7 polymer the residual BOD tended to remain constant. Several factors may cause this to happen. The first is the possibility that there may be a toxic effect taking place. The second possibility is that one, two, or all of the polymers may be removing soluble organic matter and, as this is a chemical reaction, high polymer dosages are required. While these two factors would tend to decrease the BOD with increased polymer dosages, the increase in suspended solids due to dispersion would tend to increase the BOD.

As it was visually observed that the higher molecular weight Cat Floc sample consistently formed a larger and

faster settling floc, jar test experiments were conducted to determine the effect of time of mixing, expressed as total number of paddle revolutions, and intensity of mixing on the residual BOD and suspended solids using Cat Floc Nos. 1 and 3.

Figs. 21 and 22 show the effect of revolutions of mixing at 20 rpm on the removal of BOD and suspended solids in sewage from the effluent of the University of Florida grit chamber using 2.8 mg/l of Cat Floc Nos. 1 and 3. Initially Cat Floc No. 3 seems to show a little better BOD reduction up to 300 revolutions when compared with Cat Floc No. 1. However, taking into consideration that the accuracy of the BOD test is only 5 percent, the slight difference may be considered to be insignificant. For removal of suspended solids, Fig. 22 indicates that Cat Floc No. 3 consistently gave slightly better results than Cat Floc No. 1.

Figs. 23 and 24 show the effect of revolutions of mixing at 80 rpm on the removal of BOD and suspended solids in sewage from the effluent of the Gainesville grit chamber using 9.4 mg/l of Cat Floc Nos. 1 and 3. Up to the first 500 revolutions, there is essentially no difference between the high and low molecular weights for removal of BOD and

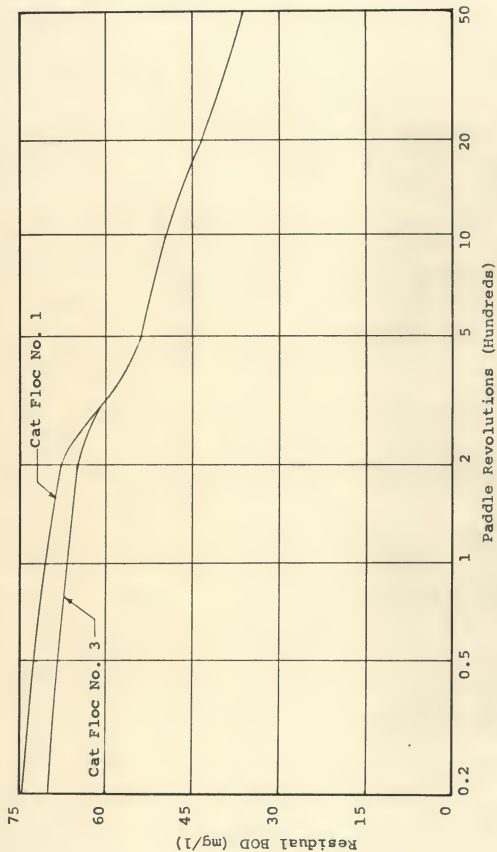


Fig. 21. Effect of Revolutions of Mixing on Removal of BOD in Sewage from the Effluent of the University of Florida Grit Chamber. Initial BOD 120 mg/l, Mixing Rate 20 rpm, Polymer Dosage 2.8 mg/l, Electrophoretic Mobility $-0.9 \mu/\text{sec}/\text{v}/\text{cm}$.

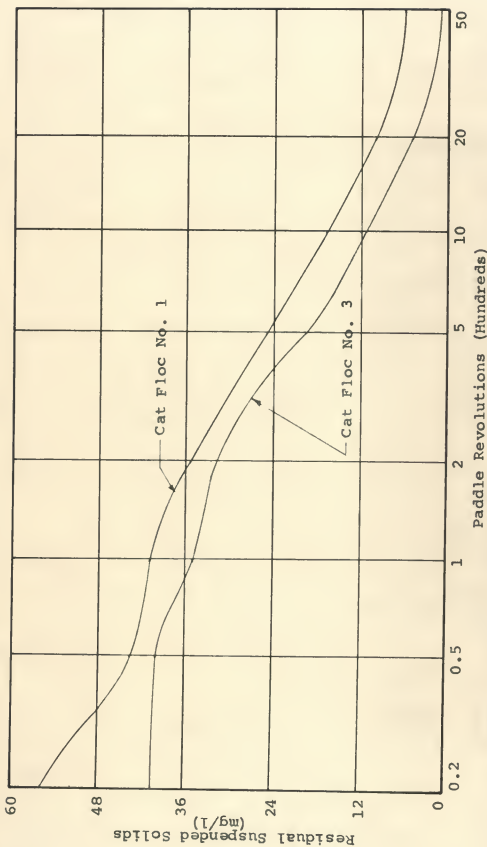


Fig. 22. Effect of Revolutions of Mixing on Removal of Suspended Solids in Sewage from the Effluent of the University of Florida Grit Chamber. Initial Suspended Solids 116 mg/l, Mixing Rate 20 rpm, Polymer Dosage 2.8 mg/l, Electrophoretic Mobility $-0.9 \mu/\text{sec}/\text{v}/\text{cm}$.

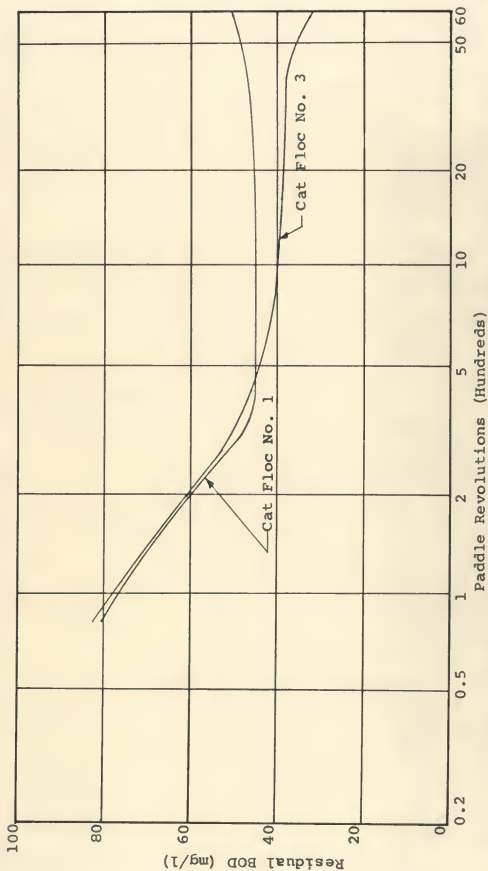


Fig. 23. Effect of Revolutions of Mixing on Removal of BOD in Sewage from the Effluent of the Gainesville Grit Chamber. Initial BOD 280 mg/l, Mixing Rate 80 rpm, Polymer Dosage 9.4 mg/l, Electrophoretic Mobility $-0.6 \mu\text{sec/v/cm}$.

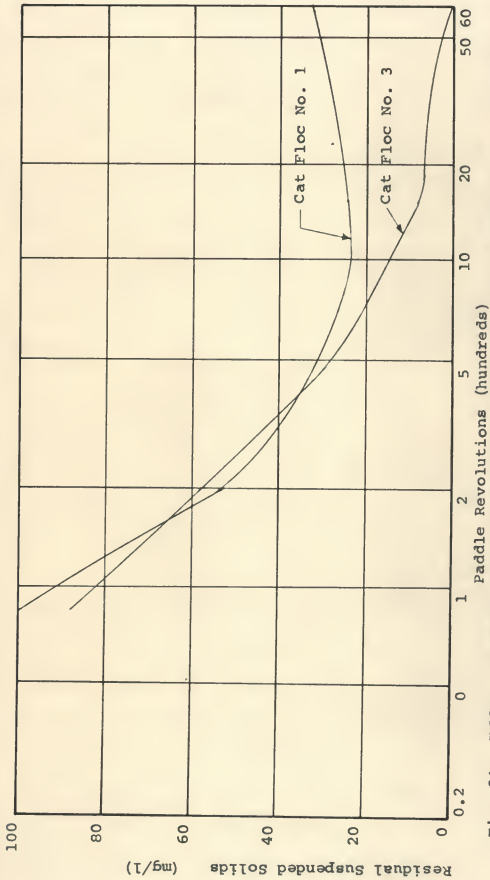


Fig. 24. Effect of Revolutions of Mixing on Removal of Suspended Solids in Sewage from the Effluent of the Gainesville Grit Chamber. Initial Suspended Solids 136 mg/l, Mixing Rate 80 rpm, Polymer Dosage 9.4 mg/l, Electrophoretic Mobility $-0.6 \mu/\text{sec}/\text{v}/\text{cm}$.

suspended solids. With further mixing an extremely important difference between the Cat Floc samples becomes evident. That is, as floc continue to grow in size under conditions of high shearing forces, the floc formed by the low molecular weight polymer tends to break up, resulting in higher BOD and suspended solids residuals, while the floc formed by the higher molecular weight polymer increases in size, resulting in lower BOD and suspended solids residuals. This factor may be of considerable importance in design, as the kinetics of coagulation-flocculation are a function of total revolutions and not of mixing time. A higher molecular weight polymer would allow higher mixing rates and therefore shorter detentions times to obtain a given removal efficiency.

Fig. 25 shows the effect of revolutions of mixing at 20 rpm on the removal of BOD and suspended solids in sewage from the effluent of the University of Florida grit chamber with no polymer added. The object of this experiment was to determine if mixing itself was capable of lowering the BOD and suspended solids. An inspection of Fig. 25 indicates that extended mixing in itself is not capable of lowering BOD and suspended solids. The slight drop in BOD after 50 minutes of mixing is probably due to either chemical or biological oxidation.

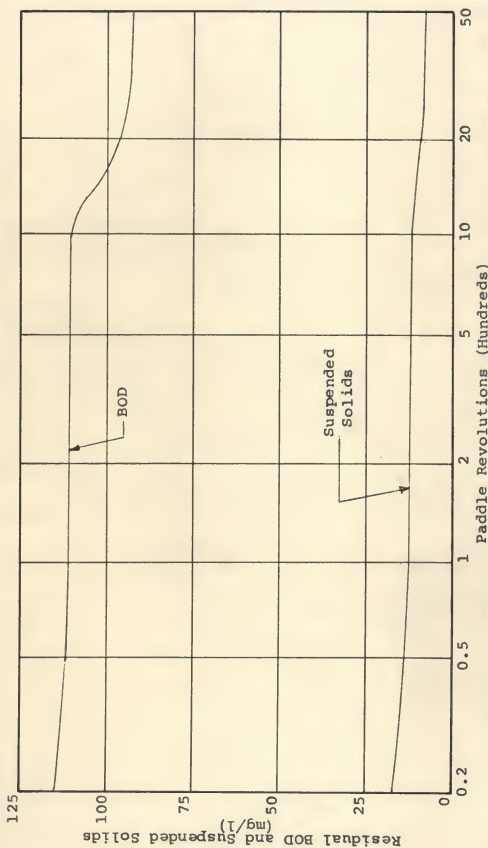


Fig. 25. Effect of Revolutions of Mixing on Removal of BOD and Suspended Solids in Sewage from the Effluent of the University of Florida Grit Chamber.
Initial BOD 120 mg/l, Initial Suspended Solids 103 mg/l, Mixing Rate 20 rpm, Polymer Dosage 0.0 mg/l, Electrophoretic Mobility $-1.5 \mu\text{sec/v/cm}$.

Experiments were conducted to determine what effect increasing pH values with Ca(OH)_2 would have on the efficiency of Cat Floc No. 3 for removing BOD and suspended solids from unsettled sewage. Results of experiments run at pH 7.5, 8.2, 9.3, and 10.3 are recorded in Tables 25 through 28.

Figs. 26 and 27 show the results of coagulation-flocculation experiments for the removal of BOD and suspended solids in sewage from the effluent of the Gainesville grit chamber, using Cat Floc No. 3 at pH 7.5 and 10.3. For a pH of 7.5, Ca(OH)_2 was not added but 185 mg/l Ca(OH)_2 was necessary to raise the pH of the sewage to 10.3. Figs. 26 and 27 show that the divalent calcium ions are effective in changing the electrophoretic mobilities, as it can be seen that the mobilities of the samples containing 185 mg/l Ca(OH)_2 consistently showed a more positive value than samples containing no Ca(OH)_2 . At pH 10.3 the lowest residual BOD obtained was 27 mg/l, while at pH 7.5 a residual BOD of 40 mg/l at optimum polymer dosage was achieved. Throughout the polymer dose range, samples raised to pH 10.3 with Ca(OH)_2 showed a slightly better efficiency in removing BOD. Fig. 27 shows that at pH 10.3 a significant difference in suspended solids exists between samples at pH 7.5 and

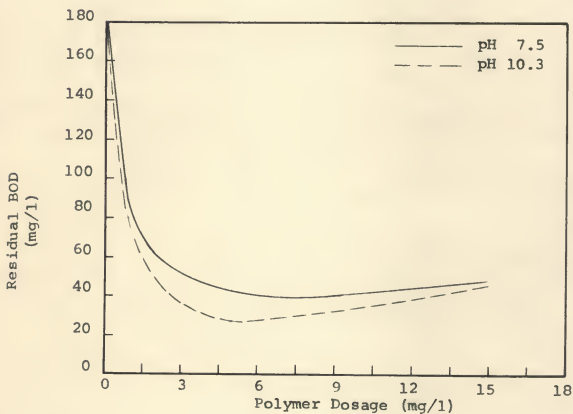
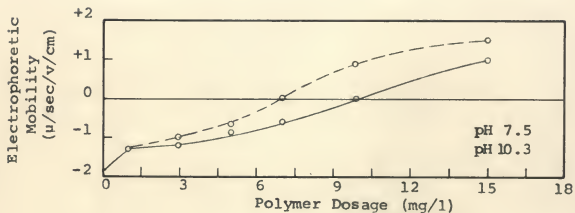


Fig. 26. Effect of pH and Various Dosages of Cat Flocc No. 3 on Removal of BOD in Sewage from the Effluent of the Gainesville Grit Chamber.

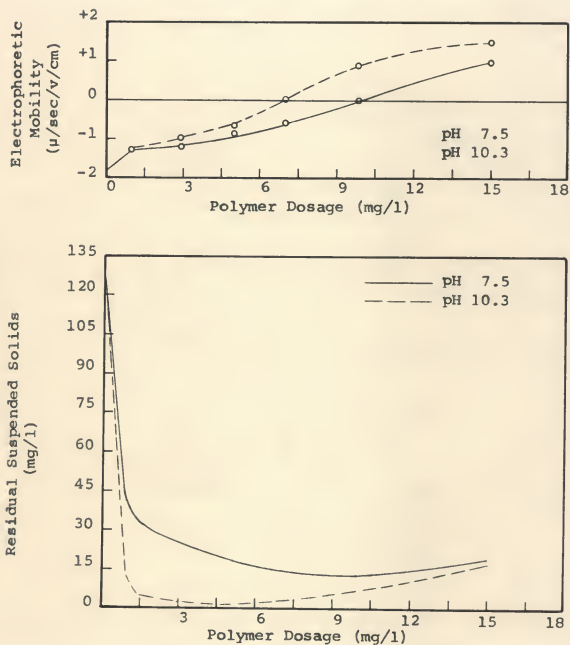


Fig. 27. Effect of pH and Various Dosages of Cat Floc No. 3 on Removal of Suspended Solids in Sewage from the Effluent of the Gainesville Grit Chamber.

pH 10.3, especially at low polymer dosages.

Fig. 28 shows the effect of various dosages of Cat Flocc No. 2 on the removal of COD and BOD in waste water from Koppers Company, Inc. The optimum electrophoretic mobility range was found to be between -0.3 and $0.0 \mu/\text{sec}/\text{v}/\text{cm}$. COD was reduced from $10,000 \text{ mg}/\text{l}$ to $2,350 \text{ mg}/\text{l}$, and the BOD from $4,800 \text{ mg}/\text{l}$ to $1,300 \text{ mg}/\text{l}$. After coagulation-flocculation at optimum polymer dosage, the resulting supernatant contained no emulsified oil particles but had a high color. This indicates that the COD and BOD reduction was due to the complete removal of the oil emulsion and the residual COD and BOD was due to the remaining dissolved organic matter.

Table 1 gives the results of coagulation-flocculation experiments on the removal of COD and BOD in waste water from the Glidden Company, using Cat Flocc No. 2 and Dow C-31. The values in Table 1 are the results at the optimum polymer dosage.

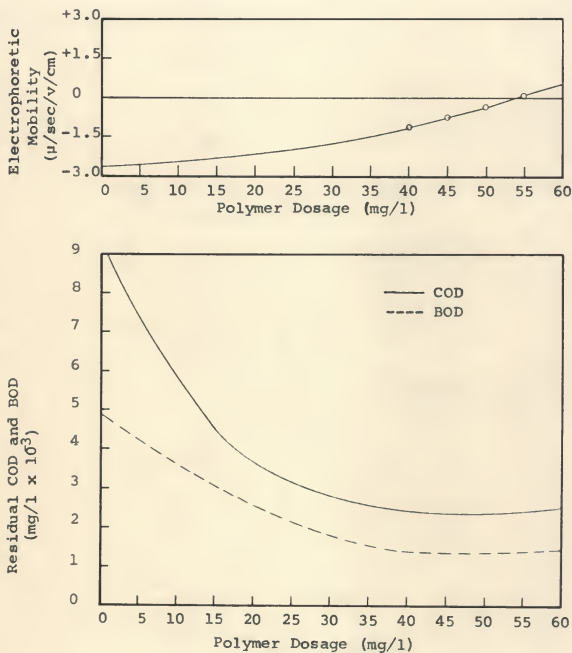


Fig. 28. Effect of Various Dosages of Cat Floc No. 2 on Removal of COD and BOD in Waste Water from Koppers Co., Inc., Forest Products Division, Gainesville, Florida. Initial COD 10,000 mg/l.

TABLE 1

EFFECT OF OPTIMUM POLYMER DOSAGE OF CAT FLOC NO. 2
AND DOW C-31 ON THE REMOVAL OF COD AND BOD IN
WASTE WATER FROM THE GLIDDEN COMPANY

Polymer Dose	Residual COD (mg/l)	Residual BOD (mg/l)	Residual Suspended Solids (mg/l)
None (Raw waste)	4,200	1,750	195
3.5 mg/l (Cat Floc No. 2)	2,780	1,314	1
14 mg/l (Dow C-31)	2,775	1,170	1

Settling of Activated Sludge

Fig. 29 shows the effect of suspended solids concentration on the settling rate of activated sludge from the Daytona Beach sewage treatment plant. It can easily be seen that suspended solids concentration has a marked effect on the settling rate, with an increase in suspended solids resulting in a decrease in settling rate. The settling rate for a suspended solids concentration of 1,000 mg/l was 18.4 ft/hr, while for suspended solids of 2,000 and 4,000 mg/l the settling rates were 10.0 and 5.0 ft/hr respectively.

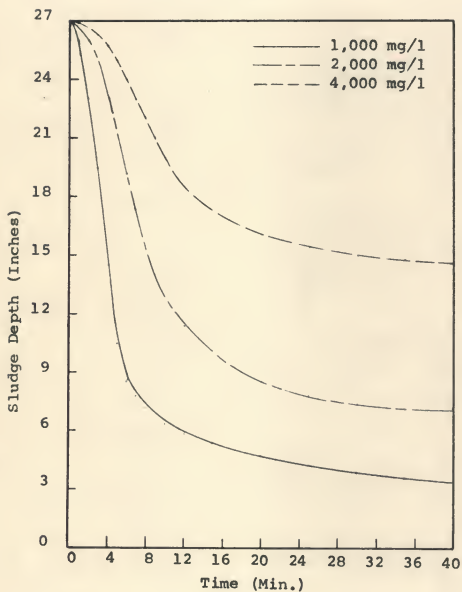


Fig. 29. Effect of Suspended Solids Concentration on the Settling Rate of Activated Sludge from the Daytona Beach Sewage Treatment Plant.

To demonstrate the reproducibility of settling of activated sludge in the special settling tubes used in this research, a settling experiment was conducted using identical samples in all four tubes. Fig. 30 shows that one settling curve was found for all settling tubes, demonstrating that there is no apparent variation from tube to tube.

La Mer et al.¹³ have shown that subsidence and filtration of phosphate slimes when treated with polyelectrolyte are greatly affected by mixing rates. They found there was an optimum amount of mixing required to provide the highest subsidence and filtration rates and that any mixing above or below the optimum gave poorer results. Fig. 31 shows the effect of mixing on the settling rate of activated sludge from the University of Florida sewage treatment plant treated with 7 mg/l of Cat Floc No. 3. The activated sludge had a suspended solids concentration of 1,500 mg/l and a sludge volume index of 680. Fair and Geyer⁸⁵ define a sludge having a sludge volume index over 200 as a bulking sludge; therefore, the activated sludge used in this experiment was an example of an extremely bulked sludge. In this experiment mixing was provided by inverting the tubes 3, 10, or 30 times. From Fig. 31 it can be seen that the greater amount of mixing caused a lag

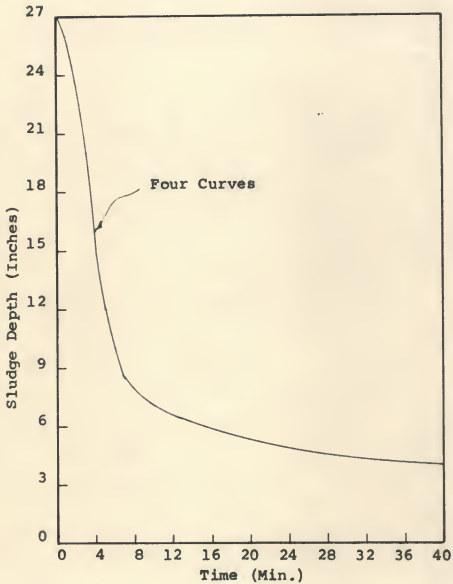


Fig. 30. Effect of Duplicate Samples on the Settling Rate of Activated Sludge from the Daytona Beach Sewage Treatment Plant. Polymer Dosage 0.0 mg/l, Suspended Solids 1,450 mg/l, SVI 120.

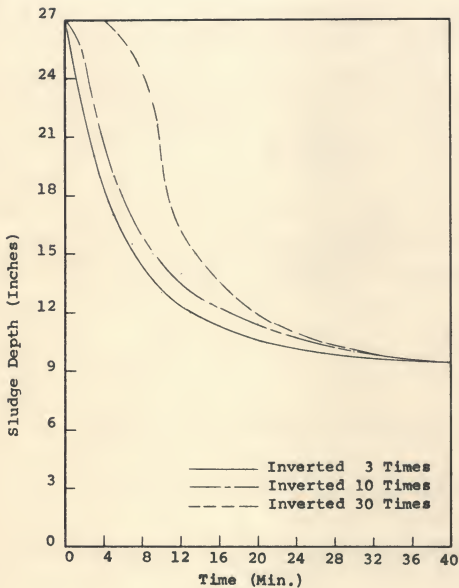


Fig. 31. Effect of Mixing on the Settling Rate of Activated Sludge from the University of Florida Sewage Treatment Plant. Polymer Dosage 7 mg/l, Suspended Solids 1,500 mg/l, SVI 680.

period of very slow flocculation followed by more rapid flocculation and settling, which was actually faster than for the sludge which was not mixed as much.

Figs. 32 through 37 show the effect of three Cat Floc samples on the settling rate of activated sludge from the Daytona Beach sewage treatment plant. Polymer dosages ranged from 1.0 to 20.0 mg/l, and activated sludge suspended solids varied from 785 to 980 mg/l. The sludge volume index ranged from 150 to 200 which, according to Fair and Geyer,⁸⁵ would classify the activated sludge as a poor settling sludge.

Figs. 32 through 37 show that polymer molecular weight has a definite effect on the rate of settling and compaction of activated sludge. Cat Floc No. 3, the highest molecular weight sample, consistently produced higher sludge settling rates than the lower molecular weight samples. An analysis of Fig. 34 by methods described in Appendix B illustrates the effect 5 mg/l of the three Cat Floc samples had on the sludge settling rates. The zone settling rate of the untreated activated sludge was 12.8 ft/hr, while 5 mg/l of Cat Floc Nos. 1, 2, and 3 increased the zone settling rate to 33.8, 42.0, and 54.0 ft/hr respectively. Assuming

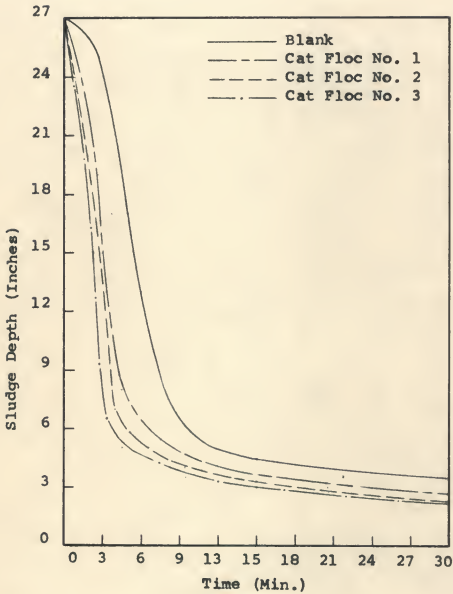


Fig. 32. Effect of Three Cat Floc Samples on the Settling Rate of Activated Sludge from the Daytona Beach Sewage Treatment Plant. Polymer Dosage 1.0 mg/l, Suspended Solids 810 mg/l, SVI 150.

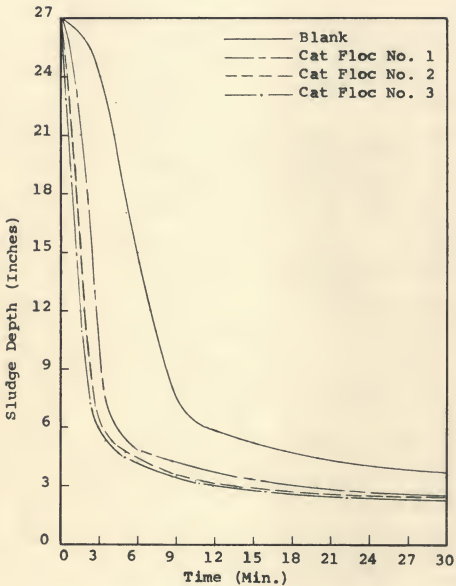


Fig. 33. Effect of Three Cat Floc Samples on the Settling Rate of Activated Sludge from the Daytona Beach Sewage Treatment Plant. Polymer Dosage 3.0 mg/l, Suspended Solids 835 mg/l, SVI 170.

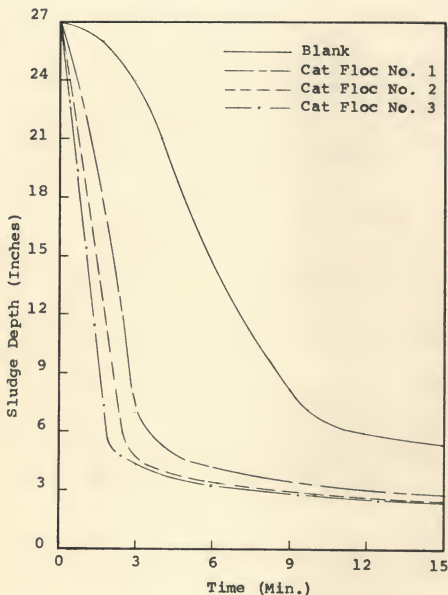


Fig. 34. Effect of Three Cat Floc Samples on the Settling Rate of Activated Sludge from the Daytona Beach Sewage Treatment Plant. Polymer Dosage 5.0 mg/l, Suspended Solids 785 mg/l, SVI 170.

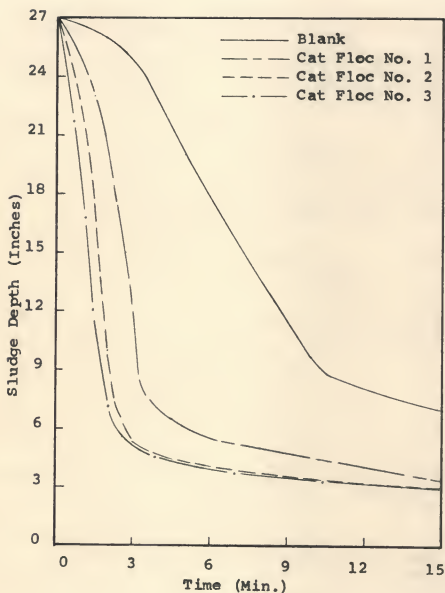


Fig. 35. Effect of Three Cat Floc Samples on the Settling Rate of Activated Sludge from the Daytona Beach Sewage Treatment Plant. Polymer Dosage 7.0 mg/l, Suspended Solids 920 mg/l, SVI 200.

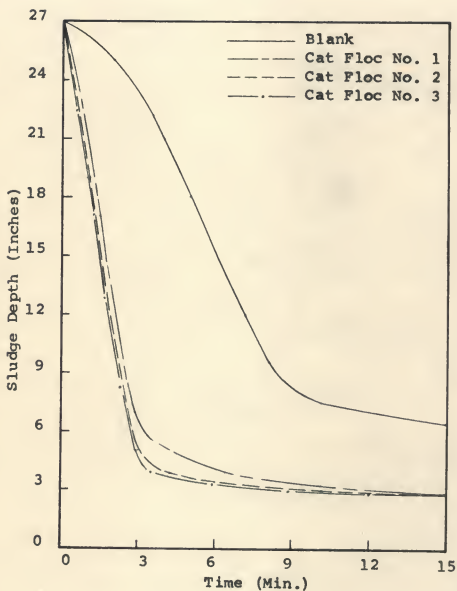


Fig. 36. Effect of Three Cat Floc Samples on the Settling Rate of Activated Sludge from the Daytona Beach Sewage Treatment Plant. Polymer Dosage 10.0 mg/l, Suspended Solids 835 mg/l, SVI 200.

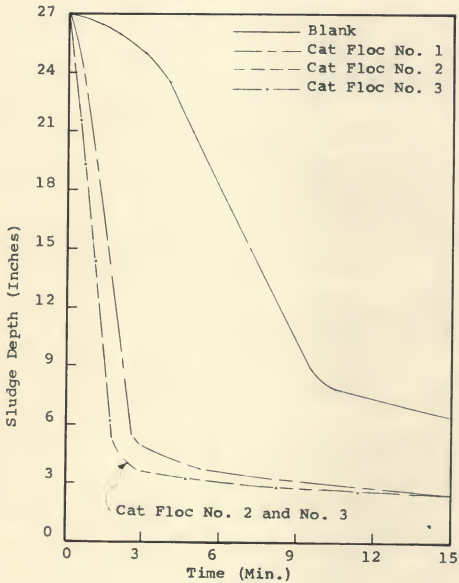


Fig. 37. Effect of Three Cat Floc Samples on the Settling Rate of Activated Sludge from the Daytona Beach Sewage Treatment Plant. Polymer Dosage 20.0 mg/l, Suspended Solids 980 mg/l, SVI 170.

a settling tank overflow rate of $1 \text{ ft}^3/\text{sec}$, the required settling area to clarify the untreated sludge would be 280 ft^2 , while the settling area required to clarify the sludge treated with 5 mg/l of Cat Floc Nos. 1, 2, and 3 would be 106, 86, and 67 ft^2 respectively. This shows that by adding 5 mg/l of Cat Floc No. 3 the required settling area for clarification could be reduced by a factor greater than 4. If an underflow concentration of $8,000 \text{ mg/l}$ is desired, an area of 347 ft^2 would be required for the untreated sludge, and an area of 146 ft^2 for the sludge treated with 5 mg/l of Cat Floc No. 3. Again this shows that by adding 5 mg/l of Cat Floc No. 3 the required settling area for thickening would be reduced by a factor greater than 2.

Figs. 38 through 44 show the effect of three Cat Floc samples on the settling rate of activated sludge from the University of Florida sewage treatment plant. Polymer dosage ranged from 1.0 to 40.0 mg/l , and activated sludge suspended solids varied from $1,200$ to $1,500 \text{ mg/l}$. The sludge volume index ranged from 520 to 770 , which means that the activated sludge was an extreme example of bulking sludge. An examination of Figs. 32 through 37 again demonstrates the effect of polymer molecular weight, with Cat

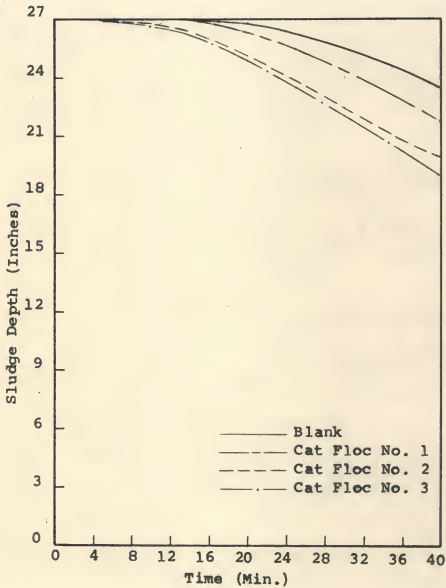


Fig. 38. Effect of Three Cat Floc Samples on the Settling Rate of Activated Sludge from the University of Florida Sewage Treatment Plant. Polymer Dosage 1.0 mg/l, Suspended Solids 1,200 mg/l, SVI 770.

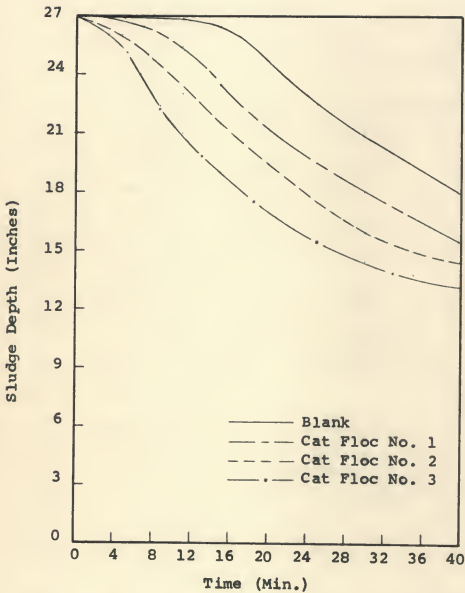


Fig. 39. Effect of Three Cat Floc Samples on the Settling Rate of Activated Sludge from the University of Florida Sewage Treatment Plant. Polymer Dosage 3.0 mg/l, Suspended Solids 1,200 mg/l, SVI 650.

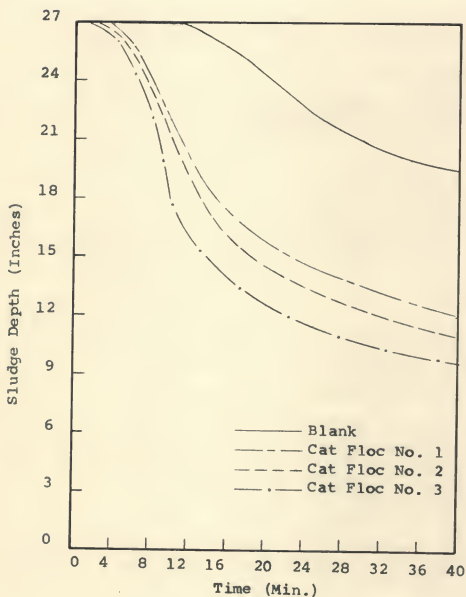


Fig. 40. Effect of Three Cat Floc Samples on the Settling Rate of Activated Sludge from the University of Florida Sewage Treatment Plant. Polymer Dosage 5.0 mg/l, Suspended Solids 1,200 mg/l, SVI 650.

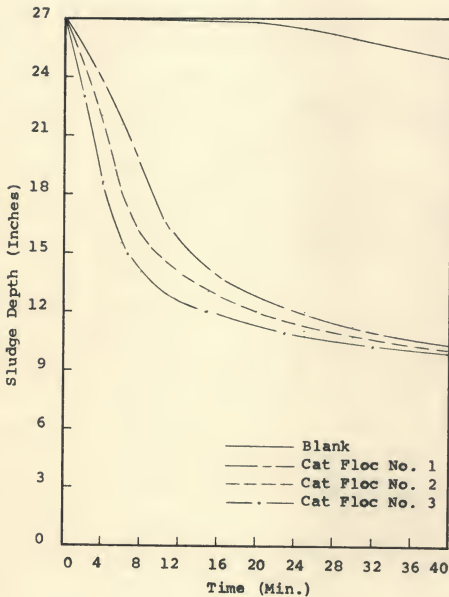


Fig. 41. Effect of Three Cat Floc Samples on the Settling Rate of Activated Sludge from the University of Florida Sewage Treatment Plant. Polymer Dosage 7.0 mg/l, Suspended Solids 1,500 mg/l, SVI 640.

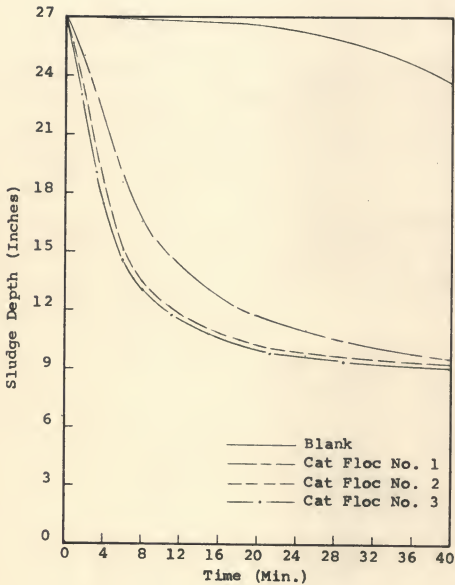


Fig. 42. Effect of Three Cat Floc Samples on the Settling Rate of Activated Sludge from the University of Florida Sewage Treatment Plant. Polymer Dosage 10.0 mg/l, Suspended Solids 1,500 mg/l, SVI 630.

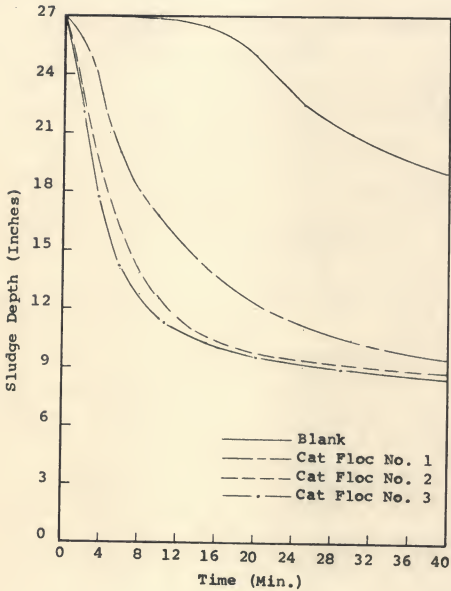


Fig. 43. Effect of Three Cat Floc Samples on the Settling Rate of Activated Sludge from the University of Florida Sewage Treatment Plant. Polymer Dosage 20.0 mg/l, Suspended Solids 1,500 mg/l, SVI 520.

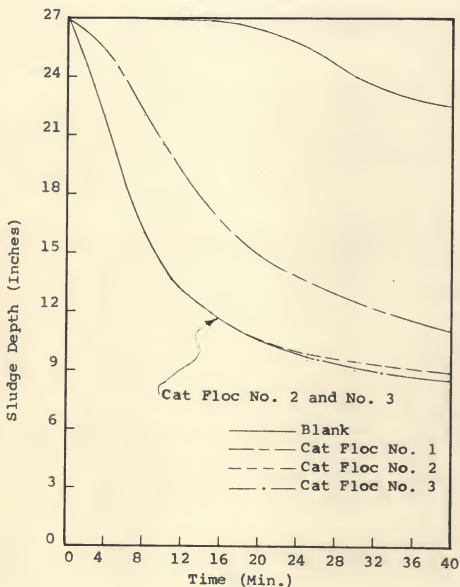


Fig. 44. Effect of Three Cat Floc Samples on the Settling Rate of Activated Sludge from the University of Florida Sewage Treatment Plant. Polymer Dosage 40.0 mg/l, Suspended Solids 1,500 mg/l, SVI 590.

Floc No. 3 consistently giving faster settling rates than Cat Floc No. 1 or No. 2. An analysis of Fig. 42 by methods described in Appendix B illustrates the effect 10.0 mg/l of the three Cat Floc samples had on the sludge settling rates. The untreated sludge settled only a little over three inches in 40 minutes, making it impossible to determine the settling rate without extending the settling test for a longer period of time. This indicates that this sludge would be almost impossible to clarify with any reasonable surface area or detention time. An inspection of the operating records of the University of Florida sewage treatment plant indicated that this was indeed the case, as no activated sludge had been wasted for a period of several months prior to the date of the settling test because of the large volume of solids lost over the weirs. After addition of 10 mg/l polymer, the settling tank area required for clarification of an overflow rate of $1 \text{ ft}^3/\text{sec}$ would be 542, 342, and 268 ft^2 for Cat Floc Nos. 1, 2, and 3 respectively. To obtain a sludge underflow concentration of 8,000 mg/l using 10 mg/l of Cat Floc Nos. 1, 2, and 3 would require surface areas of 935, 790, and 760 ft^2 respectively. This shows that activated sludge settling rates

can be increased considerably by flocculation with Cat Floc and that the higher molecular weight Cat Floc sample is most effective.

Vacuum Filtration

Fig. 45 shows the effect of various dosages of Cat Floc Nos. 1, 2, and 3 on dewatering an anaerobically digested sludge from the University of Florida sewage treatment plant. The sludge used in this filter leaf test had a solids concentration of only 1.5 percent, of which 55 percent was volatile. From Fig. 45 the effect of molecular weight may easily be seen: the higher the molecular weight the greater the filter yield. At optimum dosage Cat Floc No. 1 produced only 19 gms/ft^2 dry solids while Cat Floc Nos. 2 and 3 produced 31 and 38 gm/ft^2 dry solids. This is equivalent to a rotary vacuum filter output of 0.8, 1.4, and 1.7 lbs/hr/ft^2 dry solids for Cat Floc Nos. 1, 2, and 3 respectively. It is also evident that Cat Floc No. 3 required a lower dosage to produce the maximum filter production as compared to the lower molecular weight samples, and as polymer dosage increased past the point of optimum dosage a dispersing effect took place.

Fig. 46 shows the effect of various dosages of Cat

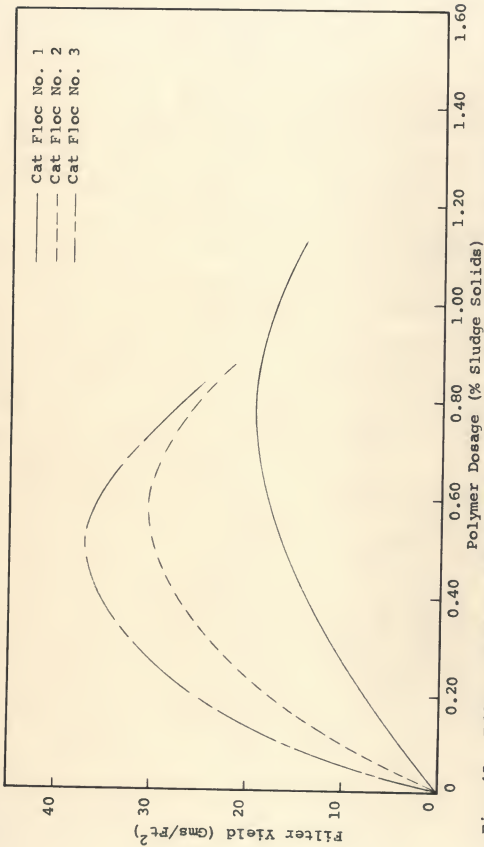


Fig. 45. Effect of Various Dosages of Three Cat Floc Samples on Dewatering of an Anaerobically Digested Sludge from the University of Florida Sewage Treatment Plant. Filter Leaf Test with Sludge Solids of 1.5 Percent.

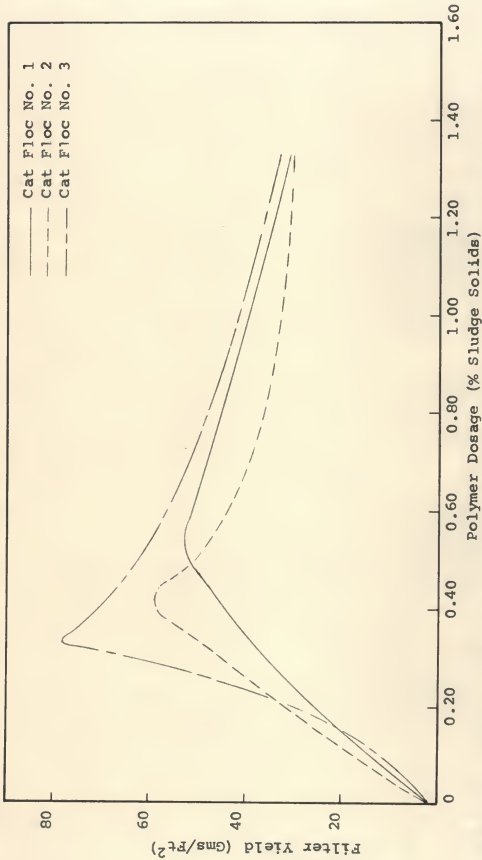


Fig. 46. Effect of Various Dosages of Three Cat Floc Samples on Dewatering of an Anaerobically Digested Sludge from the University of Florida Sewage Treatment Plant. Filter Leaf Test with Sludge Solids of 3.0 Percent.

Floc Nos. 1, 2, and 3 on dewatering an anaerobically digested sludge from the University of Florida sewage treatment plant. The sludge used in this filter leaf test had a solids concentration of 3.0 percent, of which 50 percent was volatile. Again, the effect of molecular weight is quite apparent, as Cat Floc No. 3 showed the highest filter yield. Cat Floc No. 1 produced a maximum of 53 gms/ft², while Cat Floc Nos. 2 and 3 produced 59 and 78 gms/ft² at their optimum dosage. This is equivalent to a rotary vacuum filter production of 2.3, 2.6, and 3.4 lbs/ft²/hr for Cat Floc Nos. 1, 2, and 3 respectively. Perhaps the overlapping of the curves of the three polymers may be explained by another factor which affects vacuum filtration but was held constant in this experiment and that is agitation. La Mer et al.¹⁶ found in filtration experiments on calcium phosphate that the maximum filtration rate and optimum polymer dosage varied with polyacrylamide molecular weight, time of agitation, intensity of agitation, and surface area of solids. If the effect of agitation varies with molecular weight, i.e., if each molecular weight has its own optimum agitation time and intensity, then this could possibly explain the overlapping of the curves in Fig. 46.

Fig. 47 shows the effect of various dosages of Cat Floc Nos. 1, 2, and 3 on the reduction of the specific resistance of an anaerobically digested sludge from the University of Florida sewage treatment plant. The three curves represent data determined in 23 separate Buchner funnel filtration tests. Also included in this series of tests was the effect of Dow C-31 on the reduction of the specific resistance of the same sludge. However, these data are not presented in Fig. 47 because of the higher dosages required. Data concerning the reduction of specific resistance with Dow C-31 may be found in Table 54. The initial specific resistance of the digested sludge was $2.05(10)^{10} \text{ sec}^2/\text{gm}$. The optimum dosages of Cat Floc Nos. 1, 2, and 3 lowered the specific resistance to $1.53(10)^8$, $5.14(10)^7$, and $3.69(10)^7 \text{ sec}^2/\text{gm}$ respectively. Cat Floc No. 3 reduced the specific resistance by a factor of 550, whereas Cat Floc No. 1 reduced the specific resistance by a factor of only 130, which again illustrates the great effect polymer molecular weight has in filtration efficiency. Dow C-31 was almost as effective as Cat Floc No. 3 in lowering the specific resistance. Dow C-31 lowered the specific resistance to $4.35(10)^7 \text{ sec}^2/\text{gm}$, which increased the filterability by a factor of 470.

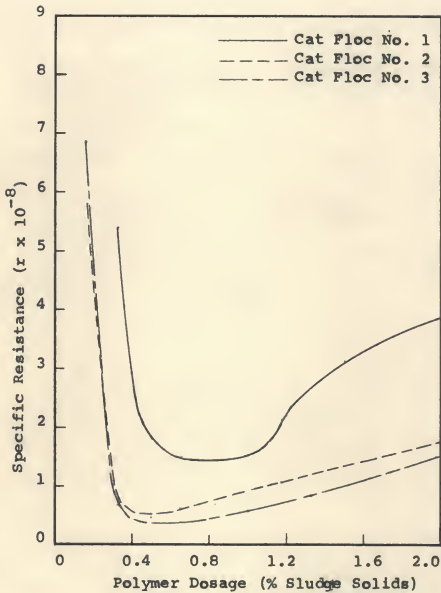


Fig. 47. Effect of Various Dosages of Three Cat Floc Samples on Reduction of the Specific Resistance of an Anaerobically Digested Sludge from the University of Florida Sewage Treatment Plant. Initial Specific Resistance $2.05 \times 10^{10} \text{ sec}^2/\text{gm}$, Sludge Solids 3.0 Percent.

V. DISCUSSION AND CONCLUSIONS

Discussion

Synthetic, high molecular weight polyelectrolytes are relative newcomers to the fields of water and waste water treatment, as they were not introduced until the early nineteen fifties. Each year new polymers are introduced, and each polymer, whether anionic, nonionic, or cationic, has its own characteristics and properties. This investigation of one particular polymer, therefore, could only shed a little light in a vast new field and raise many more questions than have been answered.

Coagulation-flocculation experiments on settled and unsettled raw sewage with three different molecular weights showed that molecular weight caused no apparent effect on the over-all BOD and suspended solids removal efficiency and caused no change in electrophoretic mobility values. However, visual observations indicated that the higher molecular weight sample produced larger and faster settling floc. Cat Floc was able to remove over 80 percent

of the BOD and 95 percent of the suspended solids from raw sewage, which can be considered to be equivalent to the removal efficiency of a trickling filter plant. Effective coagulation-flocculation was achieved over a wide range of electrophoretic mobility values, indicating that polymer dosage would not be as critical in a plant-scale operation as it would be if the optimum polymer dosage covered only a very narrow range. The low polymer dosage required, the insignificant increase in sludge solids, the low detention time, and over-all efficiency make coagulation-flocculation of raw sewage with Cat Flocc an attractive unit process for waste water treatment. A combination of coagulation-flocculation of raw sewage followed by filtration and some form of tertiary treatment to remove the dissolved organic and inorganic materials has a possible future for conversion of domestic waste water into drinking water.

A comparison between Cat Flocc No. 3, Dow C-31, and Primaflocc C-7 indicated that the three were about equally effective for removal of BOD and suspended solids. Although Dow C-31 and Primaflocc C-7 required several times more polymer to achieve the same results, this has little significance unless the cost per unit weight of each polymer is known.

Experiments using Cat Flocc Nos. 1 and 3 to determine

the effect of molecular weight on rates of coagulation-flocculation of raw sewage showed that the higher molecular weight material was more efficient in suspended solids removal at a mixing rate of 20 rpm and considerably more resistant to floc break-up at 80 rpm. As coagulation-flocculation efficiency is dependent on total number of paddle revolutions, the higher molecular weight polymer would allow higher mixing rates, thereby reducing the over-all retention time in actual plant-scale operation.

The discharge of raw sewage and effluents from sewage treatment plants containing nitrogen and phosphorous has been associated with the growth of algae blooms adversely affecting the quality of water supplies and recreational areas. Removal of phosphates from sewage and treated sewage effluents by treatment with lime has proved to be effective. However, a considerable volume of slow settling sludge is produced. Results of the present investigation show that Cat Floc and lime may be used to effectively remove BOD and suspended solids and produce a fast settling floc.

In coagulation-flocculation of industrial wastes with iron and aluminum salts, large volumes of sludge are often produced from which it is difficult to separate the

original suspended material that may be of commercial value. This handicap is overcome by the use of Cat Floc, as the polymer dosage required is low, which results in a sludge consisting mainly of the original suspended matter. Results obtained from the coagulation-flocculation of two industrial waste waters showed that Cat Floc was effective in removing all of the suspended matter and that no difficulty should be experienced in the recovery of the resulting sludge.

An area which shows much promise and one in which considerable research work needs to be done is chemical flocculation of microorganisms in biological waste treatment. Many investigators have shown that removal of BOD takes place in the first few minutes of aeration in the activated sludge process and that the additional aeration time is necessary only to facilitate the separation of the microorganisms from the effluent. Results obtained during this investigation show that Cat Floc can effectively increase the settling rates of activated sludge by flocculation of the microorganisms. This is of interest in the operation of existing activated sludge plants that are experiencing difficulty with sludge settling as well as of

interest to design engineers as a new process to be utilized in the design of future sewage treatment plants. In this investigation, polymer molecular weight proved to have a definite effect on activated sludge settling rates, with the higher molecular weight Cat Floc sample consistently producing the faster settling rate.

Polyelectrolytes have found their greatest acceptance and application in the field of sewage treatment for sludge dewatering. The use of polymers for sludge dewatering has many advantages over the inorganic chemicals, including higher filter yields, lower chemical dosages, and less corrosion of equipment. There is little doubt that, as cheaper and more effective polymers become available, they will replace inorganic chemicals presently used for this purpose.

Cat Floc has been effectively demonstrated to be an excellent sludge dewatering agent, as it lowered the specific resistance of an anaerobically digested sludge by a factor greater than five hundred. The effect of molecular weight on efficiency of dewatering proved to be highly significant. The ability of the higher molecular weight Cat Floc sample to consistently produce higher

vacuum filter yields and lower specific resistances is of extreme importance in the production of this chemical. In looking back over the results of this research work, it is apparent that the higher molecular weight material would be the most desirable for all applications in waste water treatment.

For many years the field of waste water treatment has witnessed few new developments in technology. The most important development since the activated sludge process has been the introduction of polyelectrolytes, which presents the sanitary engineer with a significant new tool whose potential uses and applications are limited only by his imagination.

Conclusions

The following principal conclusions can be drawn as a result of this investigation.

First, in coagulation-flocculation of domestic waste water, Cat Floc was highly successful in removing BOD and suspended solids.

Second, in coagulation-flocculation of domestic waste water with three different polymer molecular weights,

there was little variation in over-all treatment efficiency due to molecular weight; however, the higher molecular weight polymer did produce a floc more resistant to break-up.

Third, in flocculation and settling of activated sludge, Cat Floc proved to be extremely effective for increasing the settling rates of sludge.

Fourth, in flocculation and settling of activated sludge with three different polymer molecular weights, there was a significant difference in the settling rates, with the higher molecular weight Cat Floc sample consistently giving faster settling rates.

Fifth, Cat Floc proved to be an effective dewatering agent for anaerobically digested sludge, capable of increasing the yield of vacuum filters and lowering the specific resistance with low polymer dosages.

Sixth, in vacuum filtration of anaerobically digested sludge with three different polymer molecular weights, the higher molecular weight sample consistently produced higher vacuum filter yields and higher reductions in specific resistance.

APPENDICES

APPENDIX A

TABLES 2 THROUGH 54 :
TABULATED RESULTS OF ALL EXPERIMENTS

TABLE 2

EFFECT OF VARIOUS DOSAGES OF CAT FLOC NO. 1 ON REMOVAL
OF BOD AND SUSPENDED SOLIDS IN SEWAGE FROM THE
EFFLUENT OF A UNIVERSITY OF FLORIDA
PRIMARY SETTLING TANK

Polymer Dosage mg/l	Suspended Solids mg/l	BOD mg/l	Final pH	Electro- phoretic Mobility $\mu/\text{sec}/\text{v}/\text{cm}$
0.0*	31	50	7.60	-1.9
0.5	26	30	. .	-1.5
0.9	24	30	. .	-1.3
1.9	13	21	. .	-1.1
2.8	10	10	. .	-0.4
3.7	13	10	. .	0.0
4.7	19	7	. .	. .
5.6	14	8	. .	. .
6.6	16	8	. .	+0.7
7.5	12	10	. .	+0.8
9.4	14	7	. .	+1.0
11.2	21	10	. .	+1.1

*Effect of 0.0 polymer dose from raw sample
not a blank.

TABLE 3

EFFECT OF VARIOUS DOSAGES OF CAT FLOC NO. 2 ON REMOVAL
OF BOD AND SUSPENDED SOLIDS IN SEWAGE FROM THE
EFFLUENT OF A UNIVERSITY OF FLORIDA
PRIMARY SETTLING TANK

Polymer Dosage mg/l	Suspended Solids mg/l	BOD mg/l	Final pH	Electro- phoretic Mobility $\mu/\text{sec}/\text{v}/\text{cm}$
0.0*	31	50	7.60	-1.9
0.5	28	37	. .	-1.4
0.9	21	31	. .	-1.3
1.9	12	18	. .	-1.1
2.8	14	9	. .	-0.3
3.7	10	6	. .	-0.4
4.7	. .	. .	. .	. .
5.6	. .	. .	. .	. .
6.6	17	7	. .	+1.0
7.5	19	10	. .	+1.0
9.4	14	20	. .	+1.2
11.2	21	10	. .	+1.3

*Effect of 0.0 polymer dose from raw sample
not a blank.

TABLE 4

EFFECT OF VARIOUS DOSAGES OF CAT FLOC NO. 3 ON REMOVAL
OF BOD AND SUSPENDED SOLIDS IN SEWAGE FROM THE
EFFLUENT OF A UNIVERSITY OF FLORIDA
PRIMARY SETTLING TANK

Polymer Dosage mg/l	Suspended Solids mg/l	BOD mg/l	Final pH	Electro- phoretic Mobility $\mu/\text{sec}/\text{v}/\text{cm}$
0.0*	31	50	7.60	-1.9
0.4	26	34	. .	-1.5
0.8	26	21	. .	-1.0
1.7	13	17	. .	-0.9
2.5	2	9	. .	-0.1
3.3	13	5	. .	0.0
4.2	17	6	. .	+0.2
5.0	14	7	. .	+0.9
5.8	15	3	. .	+0.8
6.7	13	9	. .	+1.1
8.4	12	10	. .	+1.3
10.0	10	10	. .	+1.2

*Effect of 0.0 polymer dose from raw sample
not a blank.

TABLE 5

EFFECT OF VARIOUS DOSAGES OF CAT FLOC NO. 1 ON REMOVAL
OF BOD AND SUSPENDED SOLIDS IN SEWAGE FROM THE
EFFLUENT OF A GAINESVILLE
PRIMARY SETTLING TANK

Polymer Dosage mg/l	Suspended Solids mg/l	BOD mg/l	Final pH	Electro- phoretic Mobility $\mu/\text{sec}/\text{v}/\text{cm}$
0.0*	80	170	7.42	-1.8
0.5	50	165	7.49	-1.6
1.0	45	135	7.49	-1.4
3.0	53	85	7.47	-1.2
5.0	34	68	7.50	-0.9
7.0	36	55	7.58	-0.7
10.0	28	33	7.62	-0.2
12.0	33	33	7.60	+0.1
15.0	17	35	7.62	+0.3

*Effect of 0.0 polymer dose from raw sample
not a blank.

TABLE 6

EFFECT OF VARIOUS DOSAGES OF CAT FLOC NO. 2 ON REMOVAL
OF BOD AND SUSPENDED SOLIDS IN SEWAGE FROM THE
EFFLUENT OF A GAINESVILLE
PRIMARY SETTLING TANK

Polymer Dosage mg/l	Suspended Solids mg/l	BOD mg/l	Final pH	Electro- phoretic Mobility $\mu/\text{sec}/\text{v}/\text{cm}$
0.0*	80	170	7.42	-1.8
0.5	50	160	7.52	-1.5
1.0	47	130	7.46	-1.3
3.0	48	80	7.48	-1.1
5.0	36	60	7.45	-0.9
7.0	31	43	7.52	-0.7
10.0	24	29	7.61	-0.2
12.0	24	33	7.60	+0.1
15.0	35	36	7.60	+0.3

*Effect of 0.0 polymer dose from raw sample
not a blank.

TABLE 7

EFFECT OF VARIOUS DOSAGES OF CAT FLOC NO. 3 ON REMOVAL
OF BOD AND SUSPENDED SOLIDS IN SEWAGE FROM THE
EFFLUENT OF A GAINESVILLE
PRIMARY SETTLING TANK

Polymer Dosage mg/l	Suspended Solids mg/l	BOD mg/l	Final pH	Electro- phoretic Mobility $\mu/\text{sec}/\text{v}/\text{cm}$
0.0*	80	170	7.42	-1.8
0.5	46	155	7.50	-1.5
1.0	50	125	7.46	-1.3
3.0	49	75	7.49	-1.1
5.0	30	55	7.50	-0.9
7.0	8	46	7.62	-0.3
10.0	18	30	7.59	-0.1
12.0	31	32	7.56	+0.1
15.0	32	39	7.60	+0.3

*Effect of 0.0 polymer dose from raw sample
not a blank.

TABLE 8

EFFECT OF VARIOUS DOSAGES OF CAT FLOC NO. 1 ON REMOVAL
OF BOD AND SUSPENDED SOLIDS IN SEWAGE FROM THE
EFFLUENT OF THE GAINESVILLE GRIT CHAMBER

Polymer Dosage mg/l	Suspended Solids mg/l	BOD mg/l	Final pH	Electro- phoretic Mobility $\mu/\text{sec}/\text{v}/\text{cm}$
0.0*	130	152	7.27	-1.7
0.5	18	61	7.32	-1.4
0.9	13	58	7.35	-1.3
1.9	22	50	7.36	-1.2
2.8	20	37	7.36	-1.2
3.7	13	26	7.63	-1.1
4.7	13	24	7.61	-1.0
5.6	12	21	7.59	-0.9
7.5	7	19	7.55	-0.7
9.4	10	18	7.68	-0.3
11.2	11	19	7.47	0.0

*Effect of 0.0 polymer dose from raw sample
not a blank.

TABLE 9

EFFECT OF VARIOUS DOSAGES OF CAT FLOC NO. 2 ON REMOVAL
OF BOD AND SUSPENDED SOLIDS IN SEWAGE FROM THE
EFFLUENT OF THE GAINESVILLE GRIT CHAMBER

Polymer Dosage mg/l	Suspended Solids mg/l	BOD mg/l	Final pH	Electro- phoretic Mobility $\mu/\text{sec}/\text{v}/\text{cm}$
0.0*	130	152	7.27	-1.7
0.5	20	61	7.38	-1.4
0.9	20	58	7.36	-1.3
1.9	24	49	7.38	-1.2
2.8	19	37	7.36	-1.1
3.7	12	26	7.62	-1.1
4.7	13	22	7.63	-1.1
5.6	10	19	7.57	-0.9
7.5	13	18	7.50	-0.4
9.4	13	17	7.68	-0.2
11.2	12	17	7.37	-0.1

*Effect of 0.0 polymer dose from raw sample
not a blank.

TABLE 10

EFFECT OF VARIOUS DOSAGES OF CAT FLOC NO. 3 ON REMOVAL
OF BOD AND SUSPENDED SOLIDS IN SEWAGE FROM THE
EFFLUENT OF THE GAINESVILLE GRIT CHAMBER

Polymer Dosage mg/l	Suspended Solids mg/l	BOD mg/l	Final pH	Electro- phoretic Mobility $\mu/\text{sec}/\text{v}/\text{cm}$
0.0*	130	152	7.27	-1.7
0.4	19	60	7.38	-1.4
0.8	24	59	7.36	-1.3
1.7	19	49	7.35	-1.2
3.3	12	24	7.73	-1.0
4.2	10	21	7.62	-1.0
5.0	11	19	7.58	-0.9
6.7	8	18	7.52	-0.8
8.4	13	17	7.47	-0.1
10.0	14	16	7.39	+0.2

*Effect of 0.0 polymer dose from raw sample
not a blank.

TABLE 11

EFFECT OF VARIOUS DOSAGES OF CAT FLOC NO. 1 ON REMOVAL
OF BOD AND SUSPENDED SOLIDS IN SEWAGE FROM THE
EFFLUENT OF THE UNIVERSITY OF FLORIDA
GRIT CHAMBER

Polymer Dosage mg/l	Suspended Solids mg/l	BOD mg/l	Final pH	Electro- phoretic Mobility $\mu/\text{sec}/\text{v}/\text{cm}$
0.0*	95	120	8.50	-1.7
0.5	25	89	. .	-1.6
0.9	25	71	. .	-1.4
1.9	20	51	. .	-1.3
2.8	3	41	. .	-0.9
3.7	10	35	. .	-0.5
4.7	0	30	. .	-0.1
5.6	7	30	. .	+0.3
6.6	. .	. .	. .	. .
7.5	14	34	. .	+0.7
9.4	8	31	. .	+0.9
11.2	14	31	. .	+1.1

*Effect of 0.0 polymer dose from raw sample
not a blank.

TABLE 12

EFFECT OF VARIOUS DOSAGES OF CAT FLOC NO. 2 ON REMOVAL
OF BOD AND SUSPENDED SOLIDS IN SEWAGE FROM THE
EFFLUENT OF THE UNIVERSITY OF FLORIDA
GRIT CHAMBER

Polymer Dosage mg/l	Suspended Solids mg/l	BOD mg/l	Final pH	Electro- phoretic Mobility $\mu/\text{sec}/\text{v}/\text{cm}$
0.0*	95	120	8.50	-1.7
0.5	23	83	. .	-1.6
0.9	31	71	. .	-1.4
1.9	20	51	. .	-1.2
2.8	10	36	. .	-0.8
3.7	4	34	. .	-0.4
4.7	0	31	. .	-0.1
5.6	9	32	. .	+0.5
7.5	11	32	. .	+0.9
9.4	8	31	. .	+1.0
11.2	12	31	. .	+1.1

*Effect of 0.0 polymer dose from raw sample
not a blank.

TABLE 13

EFFECT OF VARIOUS DOSAGES OF CAT FLOC NO. 3 ON REMOVAL
OF BOD AND SUSPENDED SOLIDS IN SEWAGE FROM THE
EFFLUENT OF THE UNIVERSITY OF FLORIDA
GRIT CHAMBER

Polymer Dosage mg/l	Suspended Solids mg/l	BOD mg/l	Final pH	Electro- phoretic Mobility $\mu/\text{sec}/\text{v}/\text{cm}$
0.0*	95	120	8.50	-1.7
0.4	23	85	. .	-1.4
0.8	33	75	. .	-1.4
1.7	9	44	. .	-1.2
2.5	10	34	. .	-0.7
3.3	0	29	. .	-0.4
4.2	2	30	. .	+0.1
5.0	9	33	. .	+0.1
6.7	7	30	. .	+1.0
8.4	14	30	. .	+1.1
10.0	8	31	. .	+1.2

*Effect of 0.0 polymer dose from raw sample
not a blank.

TABLE 14

EFFECT OF VARIOUS DOSAGES OF CAT FLOC NO. 3 ON REMOVAL
OF BOD AND SUSPENDED SOLIDS IN SEWAGE FROM THE
EFFLUENT OF THE UNIVERSITY OF FLORIDA
GRIT CHAMBER

Polymer Dosage mg/l	Suspended Solids mg/l	BOD mg/l	Final pH	Electro- phoretic Mobility $\mu/\text{sec}/\text{v}/\text{cm}$
0.0*	106	142	8.20	-1.7
0.8	26	87	8.32	-1.4
2.5	5	54	8.42	-1.2
4.2	9	52	8.48	-0.4
5.9	7	45	8.47	+0.2
7.5	13	46	8.48	+0.9
9.2	21	48	8.49	+1.2
10.9	24	48	8.50	+1.3
12.5	28	48	8.52	+1.4

*Effect of 0.0 polymer dose from raw sample
not a blank.

TABLE 15

EFFECT OF VARIOUS DOSAGES OF DOW C-31 ON REMOVAL OF BOD
AND SUSPENDED SOLIDS IN SEWAGE FROM THE EFFLUENT OF
THE UNIVERSITY OF FLORIDA GRIT CHAMBER

Polymer Dosage mg/l	Suspended Solids mg/l	BOD mg/l	Final pH	Electro- phoretic Mobility μ /sec/v/cm
0.0*	106	142	8.20	-1.7
5.0	30	89	8.28	-1.6
10.0	15	66	8.48	-1.3
15.0	2	54	8.41	-1.2
20.0	3	49	8.43	-0.7
25.0	2	49	8.42	-0.2
30.0	5	42	8.41	+0.1
35.0	5	37	8.43	+0.3
40.0	17	35	8.43	+0.5

*Effect of 0.0 polymer dose from raw sample
not a blank.

TABLE 16

EFFECT OF VARIOUS DOSAGES OF PRIMAFLOC C-7 ON REMOVAL OF BOD
AND SUSPENDED SOLIDS IN SEWAGE FROM THE EFFLUENT OF
THE UNIVERSITY OF FLORIDA GRIT CHAMBER

Polymer Dosage mg/l	Suspended Solids mg/l	BOD mg/l	Final pH	Electro- phoretic Mobility $\mu/\text{sec}/\text{v}/\text{cm}$
0.0*	106	142	8.20	-1.7
5.0	34	89	8.25	-1.5
10.0	13	66	8.25	-1.3
13.0	3	58	8.24	-0.9
16.0	5	58	8.18	-0.5
20.0	6	57	8.10	-0.1
25.0	10	57	8.06	+0.1
30.0	9	50	7.96	+0.4
35.0	18	50	7.92	+0.9

*Effect of 0.0 polymer dose from raw sample
not a blank.

TABLE 17

EFFECT OF REVOLUTIONS OF MIXING ON REMOVAL OF BOD AND
SUSPENDED SOLIDS IN SEWAGE FROM THE EFFLUENT OF THE
UNIVERSITY OF FLORIDA GRIT CHAMBER;
POLYMER USED: CAT FLOC NO. 1

Mixing Rate 20 RPM			Polymer Dosage 2.8 mg/l	
No. of Revolutions	Suspended Solids mg/l	BOD mg/l	Final pH	Electrophoretic Mobility μ /sec/v/cm
0*	116	120	8.29	-1.9
20	57	75	. .	-0.9
50	43	73	. .	-0.9
100	41	71	. .	-0.9
200	35	66	. .	-0.9
500	25	54	. .	-0.9
1,000	17	50	. .	-0.9
2,000	10	44	. .	-0.9
5,000	6	36	. .	-0.9

*Raw sample with no polymer added not a blank.

TABLE 18

EFFECT OF REVOLUTIONS OF MIXING ON REMOVAL OF BOD AND
SUSPENDED SOLIDS IN SEWAGE FROM THE EFFLUENT OF THE
UNIVERSITY OF FLORIDA GRIT CHAMBER;
POLYMER USED: CAT FLOC NO. 2

Mixing rate 20 RPM			Polymer Dosage 2.8 mg/l	
No. of Revolutions	Suspended Solids mg/l	BOD mg/l	Final pH	Electrophoretic Mobility $\mu/\text{sec}/\text{v}/\text{cm}$
0*	116	120	8.29	-1.9
20	47	74	. .	-0.9
50	45	68	. .	-0.9
100	39	68	. .	-0.9
200	37	67	. .	-0.9
500	15	53	. .	-0.9
1,000	10	49	. .	-0.9
2,000	9	44	. .	-0.9
5,000	4	36	. .	-0.9

*Raw sample with no polymer added not a blank.

TABLE 19

EFFECT OF REVOLUTIONS OF MIXING ON REMOVAL OF BOD AND
SUSPENDED SOLIDS IN SEWAGE FROM THE EFFLUENT OF THE
UNIVERSITY OF FLORIDA GRIT CHAMBER;
POLYMER USED: CAT FLOC NO. 3

Mixing Rate 20 RPM			Polymer Dosage 2.7 mg/l	
No. of Revolutions	Suspended Solids mg/l	BOD mg/l	Final pH	Electrophoretic Mobility $\mu/\text{sec}/\text{v}/\text{cm}$
0*	116	120	8.29	-1.9
20	39	70	. .	-0.9
50	39	68	. .	-0.9
100	35	66	. .	-0.9
200	33	65	. .	-0.9
500	19	54	. .	-0.9
1,000	12	50	. .	-0.9
2,000	5	44	. .	-0.9
5,000	1	35	. .	-0.9

*Raw sample with no polymer added not a blank.

TABLE 20

EFFECT OF REVOLUTIONS OF MIXING ON REMOVAL OF BOD
AND SUSPENDED SOLIDS IN SEWAGE FROM THE EFFLUENT
OF THE GAINESVILLE GRIT CHAMBER;
POLYMER USED: CAT FLOC NO. 1

Mixing Rate 80 RPM			Polymer Dosage 9.4 mg/l	
No. of Revolutions	Suspended Solids mg/l	BOD mg/l	Final pH	Electrophoretic Mobility $\mu/\text{sec}/\text{v}/\text{cm}$
0*	136	280	7.58	-1.8
80	100	80	7.51	-0.6
200	54	61	7.73	-0.6
400	30	46	7.73	-0.6
800	24	46	7.74	-0.6
1,600	25	46	7.75	-0.6
4,000	30	46	7.78	-0.6
6,400	33	49	7.80	-0.6

*Raw sample with no polymer added not a blank.

TABLE 21

EFFECT OF REVOLUTIONS OF MIXING ON REMOVAL OF BOD
AND SUSPENDED SOLIDS IN SEWAGE FROM THE EFFLUENT
OF THE GAINESVILLE GRIT CHAMBER;
POLYMER USED: CAT FLOC NO. 2

Mixing Rate 80 RPM			Polymer Dosage 9.4 mg/l	
No. of Revolutions	Suspended Solids mg/l	BOD mg/l	Final pH	Electrophoretic Mobility $\mu/\text{sec}/\text{v}/\text{cm}$
0*	136	280	7.58	-1.8
80	90	80	7.58	-0.6
200	56	62	7.72	-0.6
400	27	44	7.72	-0.6
800	18	43	7.76	-0.6
1,600	9	38	7.78	-0.6
4,000	6	35	7.83	-0.6
6,400	1	31	7.83	-0.6

*Raw sample with no polymer added not a blank.

TABLE 22

EFFECT OF REVOLUTIONS OF MIXING ON REMOVAL OF BOD
AND SUSPENDED SOLIDS IN SEWAGE FROM THE EFFLUENT
OF THE GAINESVILLE GRIT CHAMBER;
POLYMER USED: CAT FLOC NO. 3

Mixing Rate 80 RPM			Polymer Dosage 8.4 mg/l	
No. of Revolutions	Suspended Solids mg/l	BOD mg/l	Final pH	Electrophoretic Mobility $\mu/\text{sec}/\text{v}/\text{cm}$
0*	136	280	7.58	-1.8
80	86	83	7.58	-0.6
200	58	61	7.70	-0.6
400	27	47	7.80	-0.6
800	18	40	7.83	-0.6
1,600	7	39	7.85	-0.6
4,000	5	38	7.87	-0.6
6,400	0	33	7.89	-0.6

*Raw sample with no polymer added not a blank.

TABLE 23

EFFECT OF REVOLUTIONS OF MIXING ON REMOVAL OF BOD AND
 SUSPENDED SOLIDS IN SEWAGE FROM THE EFFLUENT OF THE
 UNIVERSITY OF FLORIDA GRIT CHAMBER;
 POLYMER USED: NONE

Mixing Rate 20 RPM			Polymer Dosage 0.0 mg/l	
No. of Revolutions	Suspended Solids mg/l	BOD mg/l	Final pH	Electrophoretic Mobility $\mu/\text{sec}/\text{v}/\text{cm}$
0*	103	120	8.02	-1.5
20	16	115	8.00	-1.5
50	10	110	8.00	-1.5
100	14	115	7.96	-1.5
200	10	112	7.90	-1.5
500	12	113	7.88	-1.5
1,000	8	110	7.84	-1.5
2,000	6	94	7.80	-1.5
5,000	6	90	7.75	-1.5

*Raw sample not a blank.

TABLE 24

EFFECT OF pH ON REMOVAL OF BOD AND SUSPENDED SOLIDS IN
SEWAGE FROM THE EFFLUENT OF THE UNIVERSITY OF FLORIDA
GRIT CHAMBER DOSED WITH 2.8 mg/l OF CAT FLOC NO. 3

Polymer Dosage mg/l	Suspended Solids mg/l	BOD mg/l	Initial pH	Final pH	Electro- phoretic Mobility $\mu/\text{sec}/\text{v}/\text{cm}$
0*	84	110	7.78	7.61	-1.7
2.8	7	37	2.93	2.89	+0.1
2.8	10	38	3.80	3.78	+0.1
2.8	16	47	4.86	5.08	-1.0
2.8	13	46	5.90	6.01	-1.1
2.8	14	40	6.52	6.65	-1.3
2.8	10	44	7.52	7.45	-1.1
2.8	9	44	8.83	8.52	-1.2
2.8	14	41	9.55	9.21	-1.2
2.8	2	40	10.44	10.13	-1.2
2.8	4	38	11.06	10.82	-1.2
2.8	1	38	11.88	11.72	-1.2

*Effect of 0.0 polymer dose from raw sample
not a blank.

TABLE 25

EFFECT OF VARIOUS DOSAGES OF CAT FLOC NO. 3 ON REMOVAL
OF BOD AND SUSPENDED SOLIDS IN SEWAGE FROM THE
EFFLUENT OF THE GAINESVILLE GRIT CHAMBER,
APPROXIMATE pH 7.5

Polymer Dosage mg/l	Suspended Solids mg/l	BOD mg/l	Final pH	Electro- phoretic Mobility μ /sec/v/cm
0.0*	125	180	7.48	-1.8
1.0	29	80	7.48	-1.3
3.0	24	52	7.42	-1.2
5.0	18	42	7.42	-0.9
7.0	14	40	7.42	-0.6
10.0	12	42	7.48	0.0
15.0	23	48	7.48	+1.0

*Effect of 0.0 polymer dose from raw sample
not a blank.

TABLE 26

EFFECT OF VARIOUS DOSAGES OF CAT FLOC NO. 3 ON REMOVAL
OF BOD AND SUSPENDED SOLIDS IN SEWAGE FROM THE
EFFLUENT OF THE GAINESVILLE GRIT CHAMBER,
APPROXIMATE pH 8.2

Polymer Dosage mg/l	Suspended Solids mg/l	BOD mg/l	Final pH	Electro- phoretic Mobility $\mu/\text{sec}/\text{v}/\text{cm}$
0.0*	125	180	7.48	-1.8
1.0	35	110	8.10	-1.2
3.0	22	47	8.17	-1.1
5.0	9	38	8.31	-0.8
7.0	7	36	8.23	-0.3
10.0	20	45	8.32	+0.3
15.0	27	54	8.26	+1.3

*Effect of 0.0 polymer dose from raw sample
not a blank.

TABLE 27

EFFECT OF VARIOUS DOSAGES OF CAT FLOC NO. 3 ON REMOVAL
OF BOD AND SUSPENDED SOLIDS IN SEWAGE FROM THE
EFFLUENT OF THE GAINESVILLE GRIT CHAMBER,
APPROXIMATE pH 9.3

Polymer Dosage mg/l	Suspended Solids mg/l	BOD mg/l	Final pH	Electro- phoretic Mobility $\mu/\text{sec}/\text{v}/\text{cm}$
0.0*	125	180	7.48	-1.8
1.0	20	92	9.25	-1.2
3.0	11	43	9.25	-0.9
5.0	3	35	9.25	-0.4
7.0	3	35	9.25	0.0
10.0	29	45	9.29	+0.9
15.0	37	48	9.29	+1.6

*Effect of 0.0 polymer dose from raw sample
not a blank.

TABLE 28

EFFECT OF VARIOUS DOSAGES OF CAT FLOC NO. 3 ON REMOVAL
OF BOD AND SUSPENDED SOLIDS IN SEWAGE FROM THE
EFFLUENT OF THE GAINESVILLE GRIT CHAMBER,
APPROXIMATE pH 10.3

Polymer Dosage mg/l	Suspended Solids mg/l	BOD mg/l	Final pH	Electro- phoretic Mobility $\mu/\text{sec}/\text{v}/\text{cm}$
0.0*	125	180	7.48	-1.8
1.0	5	73	10.31	-1.3
3.0	2	36	10.35	-1.0
5.0	1	27	10.28	-0.7
7.0	5	32	10.25	0.0
10.0	13	37	10.50	+0.9
15.0	21	76	10.21	+1.5

*Effect of 0.0 polymer dose from raw sample
not a blank.

TABLE 29

EFFECT OF VARIOUS DOSAGES OF CAT FLOC NO. 2 ON REMOVAL
OF COD, BOD, AND PHENOL IN WASTE WATER FROM
KOPPERS CO., INC., FOREST PRODUCTS DIVISION,
GAINESVILLE, FLORIDA

Polymer Dosage mg/l	COD mg/l	BOD mg/l	Phenol mg/l	Electro- phoretic Mobility μ /sec/v/sec
0.0*	10,000	4,800	150	-2.8
40.0	2,580	1,360	141	-1.2
45.0	2,200	1,300	140	-0.8
50.0	2,780	1,300	136	-0.4
55.0	2,340	1,410	135	0.0
60.0	2,520	1,380	136	+0.5

*Effect of 0.0 polymer dose from raw sample
not a blank.

TABLE 30

EFFECT OF SUSPENDED SOLIDS CONCENTRATION ON THE
SETTLING RATE OF ACTIVATED SLUDGE FROM THE
DAYTONA BEACH SEWAGE TREATMENT PLANT

Suspended Solids 1,000 mg/l		Suspended Solids 2,000 mg/l		Suspended Solids 4,000 mg/l	
Time Min.	Sludge Depth Inches	Time Min.	Sludge Depth Inches	Time Min.	Sludge Depth Inches
0.0	27.0	0.0	27.0	0.0	27.0
1.0	26.0	1.0	26.8	1.0	26.9
2.0	23.0	2.0	26.0	2.0	26.8
3.0	19.5	3.0	24.5	3.0	26.3
4.0	14.5	4.0	23.3	4.0	25.8
5.0	10.5	5.0	21.5	5.0	25.0
6.0	8.5	6.0	19.1	6.0	24.0
7.0	7.8	7.0	17.4	7.0	23.0
8.0	7.1	8.0	15.5	8.0	22.0
9.0	6.8	9.0	13.5	9.0	21.0
10.0	6.4	10.0	12.8	10.0	20.0
12.0	5.9	12.0	11.4	12.0	18.0
15.0	5.4	15.0	10.0	15.0	17.0
20.0	4.8	20.0	8.5	20.0	16.0
25.0	4.3	25.0	7.8	25.0	15.4
30.0	3.9	30.0	7.5	30.0	15.0
35.0	3.7	35.0	7.3	35.0	14.8
40.0	3.5	40.0	7.2	40.0	14.6

TABLE 31
EFFECT OF DUPLICATE SAMPLES ON THE SETTLING RATE OF ACTIVATED SLUDGE
FROM THE DAYTONA BEACH SEWAGE TREATMENT PLANT; POLYMER DOSE 0.0 mg/l

Suspended Solids 1450 mg/l									
Tube No. 1			Tube No. 2			Tube No. 3			SVI 120
Time Min.	Sludge Depth Inches		Time Min.	Sludge Depth Inches		Time Min.	Sludge Depth Inches		
0.0	27.0		0.0	27.0		0.0	27.0		0.0
1.0	26.0		1.0	26.0		1.0	26.0		1.0
2.0	23.0		2.0	23.0		2.0	23.0		2.0
3.0	20.0		3.0	20.0		3.0	20.0		3.0
4.0	16.0		4.0	16.0		4.0	16.0		4.0
5.0	12.0		5.0	12.0		5.0	12.0		5.0
6.0	10.0		6.0	10.0		6.0	10.0		6.0
7.0	8.5		7.0	8.5		7.0	8.5		7.0
9.0	7.5		9.0	7.5		9.0	7.5		9.0
11.0	7.0		11.0	7.0		11.0	7.0		11.0
16.0	6.0		16.0	6.0		16.0	6.0		16.0
24.0	5.0		24.0	5.0		24.0	5.0		24.0
30.0	4.6		30.0	4.6		30.0	4.6		30.0
40.0	4.0		40.0	4.0		40.0	4.0		40.0

TABLE 32

EFFECT OF MIXING ON THE SETTLING RATE OF ACTIVATED SLUDGE
FROM THE UNIVERSITY OF FLORIDA SEWAGE TREATMENT PLANT;
POLYMER DOSE 7 mg/l

Suspended Solids		1,500 mg/l		SVI 680	
Inverted 3 Times		Inverted 10 Times		Inverted 30 Times	
Time Min.	Sludge Depth Inches	Time Min.	Sludge Depth Inches	Time Min.	Sludge Depth Inches
0.0	27.0	0.0	27.0	0.0	27.0
1.0	25.0	. .	. .	. .	. .
3.0	20.0	2.0	26.5	0.5	27.0
5.0	17.0	5.0	19.0	4.5	27.0
7.0	15.5	6.0	18.0	7.5	25.0
10.0	13.0	9.0	15.0	10.5	18.0
13.0	12.0	12.0	14.0	13.5	15.0
16.0	11.5	15.0	12.5	18.5	12.5
21.0	10.5	20.0	11.5	. .	. .
30.0	10.0	30.0	10.0	30.0	10.0
40.0	9.5	40.0	9.5	40.0	9.3

TABLE 33

EFFECT OF THREE CAT FLOC SAMPLES ON THE SETTLING RATE OF ACTIVATED SLUDGE
FROM THE DAYTONA BEACH SEWAGE TREATMENT PLANT; POLYMER DOSE 1.0 mg/l

Suspended Solids 810 mg/l						SVI 150					
Blank			Cat Floc No. 1			Cat Floc No. 2			Cat Floc No. 3		
Time	Sludge Depth		Time	Sludge Depth		Time	Sludge Depth		Time	Sludge Depth	
Min.	Inches		Min.	Inches		Min.	Inches		Min.	Inches	
0.0	27.0		0.0	27.0		0.0	27.0		0.0	27.0	
2.0	26.0		1.5	23.0		1.0	24.0		0.5	26.0	
3.0	24.0		2.5	19.0		2.0	20.0		1.5	23.0	
4.0	21.0		3.5	13.0		3.0	15.0		2.5	15.0	
5.0	17.0		4.5	8.0		4.0	7.0		3.5	6.5	
6.0	13.0		5.5	6.5		5.0	5.8		4.5	5.0	
8.0	7.5		7.5	5.4		7.0	5.0		6.5	4.5	
10.0	5.9		10.0	4.5		10.0	4.0		10.0	3.6	
12.0	5.3		12.0	4.1		12.0	3.8		12.0	3.4	
15.0	4.5		15.0	3.8		15.0	3.4		15.0	3.0	
20.0	4.1		20.0	3.3		20.0	3.0		20.0	2.8	
30.0	3.3		30.0	2.8		30.0	2.4		30.0	2.3	

TABLE 34
EFFECT OF THREE CAT FLOC SAMPLES ON THE SETTLING RATE OF ACTIVATED SLUDGE
FROM THE DAYTONA BEACH SEWAGE TREATMENT PLANT; POLYMER DOSE 3.0 mg/l

Suspended Solids 835 mg/l				SVI 170			
Blank		Cat Floc No. 1		Cat Floc No. 2		Cat Floc No. 3	
Time Min.	Sludge Depth Inches	Time Min.	Sludge Depth Inches	Time Min.	Sludge Depth Inches	Time Min.	Sludge Depth Inches
0.0	27.0	0.0	27.0	0.0	27.0	0.0	27.0
2.0	26.0	1.5	21.0	1.0	25.0	0.5	25.0
3.0	24.0	2.5	13.0	2.0	12.0	1.5	11.0
4.0	21.0	3.5	7.0	3.0	6.0	2.5	7.0
5.0	17.0	4.5	6.9	4.0	5.3	3.5	5.3
6.0	15.0	5.5	5.0	5.0	4.8	4.5	4.8
7.0	12.0	6.5	4.8	6.0	4.3	5.5	4.3
9.0	7.3	8.5	4.3	8.0	3.8	7.5	3.8
10.0	6.5	9.5	4.0	9.0	3.5	8.5	3.5
12.0	5.9	11.5	3.6	11.0	3.3	10.5	3.3
15.0	5.3	14.5	3.4	14.0	3.0	13.5	3.0
20.0	4.5	20.0	3.0	20.0	2.9	20.0	2.8
30.0	3.8	30.0	2.6	30.0	2.5	30.0	2.4

TABLE 35
EFFECT OF THREE CAT FLOC SAMPLES ON THE SETTLING RATE OF ACTIVATED SLUDGE
FROM THE DAYTONA BEACH SEWAGE TREATMENT PLANT; POLYMER DOSE 5.0 mg/l

Suspended Solids 785 mg/l									
SVI 170									
Blank		Cat Floc No. 1		Cat Floc No. 2		Cat Floc No. 3			
Time	Sludge Depth	Time	Sludge Depth	Time	Sludge Depth	Time	Sludge Depth	Time	Sludge Depth
Min.	Inches	Min.	Inches	Min.	Inches	Min.	Inches	Min.	Inches
0.0	27.0	0.0	27.0	0.0	27.0	0.0	27.0	0.0	27.0
2.0	26.0	2.0	"	1.5	"	1.0	"	1.0	"
3.0	24.0	3.0	7.0	2.5	5.0	2.0	5.0	2.0	5.0
4.0	21.0	4.0	5.3	3.5	4.3	3.0	4.3	3.0	4.3
5.0	17.0	5.0	4.8	4.5	3.8	4.0	3.8	4.0	3.8
7.0	12.0	7.0	3.9	6.5	3.4	6.0	3.3	6.0	3.3
10.0	6.5	10.0	3.4	10.0	2.9	10.0	2.8	10.0	2.8
15.0	5.3	15.0	2.9	15.0	2.6	15.0	2.6	15.0	2.6
20.0	4.5	20.0	2.5	20.0	2.5	20.0	2.5	20.0	2.5
30.0	3.8	30.0	2.3	30.0	2.4	30.0	2.4	30.0	2.4

TABLE 36

EFFECT OF THREE CAT FLOC SAMPLES ON THE SETTLING RATE OF ACTIVATED SLUDGE
FROM THE DAYTONA BEACH SEWAGE TREATMENT PLANT; POLYMER DOSE 7.0 mg/l

Suspended Solids 920 mg/l						SVI 200	
Blank		Cat Floc No. 1		Cat Floc No. 2		Cat Floc No. 3	
Time Min.	Sludge Depth Inches	Time Min.	Sludge Depth Inches	Time Min.	Sludge Depth Inches	Time Min.	Sludge Depth Inches
0.0	27.0	0.0	27.0	0.0	27.0	0.0	27.0
2.0	26.0	1.5	23.0	1.0	21.0	0.5	20.0
3.0	25.0	2.5	15.0	2.0	10.0	1.5	10.0
4.0	.	3.5	8.0	3.0	5.3	2.5	5.5
5.0	20.0	4.5	6.5	4.0	4.8	3.5	4.9
7.0	15.0	6.5	5.3	6.0	4.0	5.5	4.0
10.0	8.9	10.0	4.3	10.0	3.5	10.0	3.5
15.0	7.0	15.0	3.5	15.0	3.0	15.0	3.0
20.0	6.0	20.0	3.3	20.0	3.0	20.0	3.0
30.0	5.0	30.0	2.8	30.0	2.8	30.0	3.0

TABLE 37

EFFECT OF THREE CAT FLOC SAMPLES ON THE SETTLING RATE OF ACTIVATED SLUDGE
FROM THE DAYTONA BEACH SEWAGE TREATMENT PLANT; POLYMER DOSE 10.0 mg/l

Suspended Solids 835 mg/l			SVI 200		
Blank			Cat Floc No. 1		
Time Min.	Sludge Depth Inches	Time Min.	Sludge Depth Inches	Time Min.	Sludge Depth Inches
0.0	27.0	0.0	27.0	0.0	27.0
2.0	26.0	1.5	17.0	1.0	.
3.0	.	3.0	6.0	3.0	5.0
4.0	21.0	.	.	.	.
5.0	18.0	4.5	4.8	4.0	3.5
7.0	12.0	6.5	3.9	6.0	3.5
10.0	7.5	10.0	3.3	10.0	3.0
15.0	6.5	15.0	2.9	15.0	2.9
20.0	5.5	20.0	2.8	20.0	2.8
30.0	4.6	30.0	2.5	30.0	2.8
Cat Floc No. 2			Cat Floc No. 3		
Time Min.	Sludge Depth Inches	Time Min.	Sludge Depth Inches	Time Min.	Sludge Depth Inches
0.0	27.0	0.0	27.0	0.0	27.0
2.0	17.0	1.0	19.0	.	.
3.0	6.0	3.0	5.0	3.0	5.0
4.0	.	.	.	.	.
5.0	18.0	4.0	3.9	3.5	4.0
7.0	12.0	6.0	3.3	5.5	3.5
10.0	7.5	10.0	3.0	10.0	3.0
15.0	6.5	15.0	2.9	15.0	2.9
20.0	5.5	20.0	2.8	20.0	2.8
30.0	4.6	30.0	2.6	30.0	2.8

TABLE 38
EFFECT OF THREE CAT FLOC SAMPLES ON THE SETTLING RATE OF ACTIVATED SLUDGE
FROM THE DAYTONA BEACH SEWAGE TREATMENT PLANT; POLYMER DOSE 20.0 mg/l

Suspended Solids 980 mg/l						SVI 170		
Blank			Cat Floc No. 1		Cat Floc No. 2		Cat Floc No. 3	
Time Min.	Sludge Depth Inches		Time Min.	Sludge Depth Inches	Time Min.	Sludge Depth Inches	Time Min.	Sludge Depth Inches
0.0	27.0		0.0	27.0	0.0	27.0	0.0	27.0
2.0	26.0		"	"	"	"	"	"
3.0	25.0		2.5	5.0	2.0	4.5	2.0	4.5
4.0	23.5		3.5	4.5	3.0	3.5	3.0	3.5
5.0	21.0		5.0	3.8	5.0	3.3	5.0	3.3
7.0	15.0		7.0	3.3	7.0	2.9	7.0	2.9
10.0	8.0		10.0	2.9	10.0	2.8	10.0	2.9
15.0	6.5		15.0	2.5	15.0	2.5	15.0	2.8
20.0	5.5		20.0	2.4	20.0	2.5	20.0	2.8
30.0	4.5		30.0	2.3	30.0	2.5	30.0	2.8

TABLE 39
EFFECT OF THREE CAT FLOC SAMPLES ON THE SETTLING RATE OF ACTIVATED SLUDGE
FROM THE DAYTONA BEACH SEWAGE TREATMENT PLANT; POLYMER DOSE 40.0 mg/l

Suspended Solids 875 mg/l						
SVI 170						
Blank						
Time Min.	Sludge Depth Inches	Cat Floc No. 1		Cat Floc No. 2		Cat Floc No. 3
		Time Min.	Sludge Depth Inches	Time Min.	Sludge Depth Inches	Time Min. Sludge Depth Inches
0.0	27.0	0.0	27.0	0.0	27.0	0.0 27.0
2.0	26.0	.	.	2.0	5.0	2.0 4.3
4.0	25.0	4.0	5.0	4.0	3.5	4.0 3.0
6.0	17.0	6.0	3.9	6.0	3.0	6.0 2.9
10.0	7.0	10.0	3.0	10.0	2.6	10.0 2.8
15.0	5.8	15.0	2.6	15.0	2.5	15.0 2.5
20.0	5.0	20.0	2.5	20.0	2.4	20.0 2.5
30.0	4.0	30.0	2.3	30.0	2.4	30.0 2.5

TABLE 40
EFFECT OF THREE CAT FLOC SAMPLES ON THE SETTLING RATE OF ACTIVATED SLUDGE FROM
THE UNIVERSITY OF FLORIDA SEWAGE TREATMENT PLANT; POLYMER DOSE 1.0 mg/l

Suspended Solids 1,200 mg/l						SVI 770	
Blank		Cat Floc No. 1		Cat Floc No. 2		Cat Floc No. 3	
Time Min.	Sludge Depth Inches	Time Min.	Sludge Depth Inches	Time Min.	Sludge Depth Inches	Time Min.	Sludge Depth Inches
0.0	27.0	0.0	27.0	0.0	27.0	0.0	27.0
2.0	27.0	1.5	27.0	1.0	27.0	0.5	27.0
4.0	27.0	3.5	27.0	3.0	27.0	2.5	27.0
6.0	27.0	5.5	27.0	5.0	26.9	4.5	26.9
10.0	27.0	9.5	27.0	9.0	26.9	8.5	26.9
12.0	27.0	11.5	27.0	11.0	26.8	10.5	26.9
13.0	27.0	12.5	27.0	12.0	26.7	11.5	26.9
15.0	26.9	14.5	26.9	14.0	26.5	13.5	26.7
17.0	26.9	16.5	26.8	16.0	26.0	15.5	26.5
20.0	26.8	19.5	26.5	19.0	25.0	18.5	25.5
25.0	26.0	25.0	25.5	25.0	23.5	25.0	23.5
30.0	25.0	30.0	24.0	30.0	22.5	30.0	22.0
35.0	24.5	35.0	23.0	35.0	21.0	35.0	20.3
40.0	23.5	40.0	21.8	40.0	20.0	40.0	19.0

TABLE 41
EFFECT OF THREE CAT FLOC SAMPLES ON THE SETTLING RATE OF ACTIVATED SLUDGE FROM
THE UNIVERSITY OF FLORIDA SEWAGE TREATMENT PLANT; POLYMER DOSE 3.0 mg/l

Suspended Solids 1,200 mg/l						SVI 650	
Blank		Cat Floc No. 1		Cat Floc No. 2		Cat Floc No. 3	
Time Min.	Sludge Depth Inches	Time Min.	Sludge Depth Inches	Time Min.	Sludge Depth Inches	Time Min.	Sludge Depth Inches
0.0	27.0	0.0	27.0	0.0	27.0	0.0	27.0
2.0	27.0	1.0	27.0	1.5	26.8	0.5	27.0
5.0	26.9	4.0	26.6	4.5	26.0	3.5	26.0
8.0	26.9	7.0	26.5	7.5	25.0	6.5	24.0
11.0	26.9	11.0	25.3	11.0	23.0	11.0	21.0
15.0	26.5	15.0	23.5	15.0	21.5	15.0	19.0
20.0	24.5	20.0	21.0	20.0	19.5	20.0	17.0
25.0	22.5	25.0	19.5	25.0	17.5	25.0	15.5
30.0	21.0	30.0	18.0	30.0	16.0	30.0	14.5
35.0	19.5	35.0	17.0	35.0	15.0	35.0	13.8
40.0	18.0	40.0	15.5	40.0	14.5	40.0	13.0

TABLE 42
EFFECT OF THREE CAT FLOC SAMPLES ON THE SETTLING RATE OF ACTIVATED SLUDGE FROM
THE UNIVERSITY OF FLORIDA SEWAGE TREATMENT PLANT; POLYMER DOSE 5.0 mg/l

Suspended Solids 1,200 mg/l									
SVI 650									
Blank		Cat Floc No. 1			Cat Floc No. 2			Cat Floc No. 3	
Time	Sludge Depth	Time	Sludge Depth	Time	Sludge Depth	Time	Sludge Depth	Time	Sludge Depth
Min.	Inches	Min.	Inches	Min.	Inches	Min.	Inches	Min.	Inches
0.0	27.0	0.0	27.0	0.0	27.0	0.0	27.0	0.0	27.0
2.0	27.0	2.0	27.0	2.0	27.0	2.0	27.0	2.0	26.8
4.0	27.0	4.0	27.0	4.0	26.5	4.0	26.5	4.0	26.5
10.0	27.0	10.0	22.0	10.0	21.0	10.0	21.0	10.0	18.0
12.0	27.0	12.0	20.0	12.0	19.0	12.0	19.0	12.0	16.5
15.0	25.5	15.0	17.0	15.0	16.5	15.0	16.5	15.0	14.5
20.0	24.0	20.0	16.0	20.0	14.5	20.0	14.5	20.0	12.5
25.0	23.0	25.0	14.8	25.0	13.5	25.0	13.5	25.0	11.5
30.0	21.0	30.0	13.5	30.0	12.0	30.0	12.0	30.0	11.0
35.0	20.0	35.0	13.0	35.0	11.5	35.0	11.5	35.0	10.0
40.0	19.5	40.0	12.0	40.0	11.0	40.0	11.0	40.0	9.8

TABLE 43

EFFECT OF THREE CAT FLOC SAMPLES ON THE SETTLING RATE OF ACTIVATED SLUDGE FROM
THE UNIVERSITY OF FLORIDA SEWAGE TREATMENT PLANT; POLYMER DOSE 7.0 mg/l

Suspended Solids 1,500 mg/l									
SVI 640									
Blank		Cat Floc No. 1			Cat Floc No. 2			Cat Floc No. 3	
Time Min.	Sludge Depth Inches	Time Min.	Sludge Depth Inches		Time Min.	Sludge Depth Inches		Time Min.	Sludge Depth Inches
0.0	27.0	0.0	27.0		0.0	27.0		0.0	27.0
2.0	27.0	2.0	25.8		2.0	24.5		2.0	23.0
4.0	27.0	4.0	23.5		4.0	22.0		4.0	18.5
6.0	27.0	6.0	21.5		6.0	18.0		6.0	15.5
8.0	26.9	8.0	18.0		8.0	16.0		8.0	14.0
10.0	26.9	10.0	16.8		10.0	14.5		10.0	12.5
12.0	26.9	12.0	15.5		12.0	14.0		12.0	12.5
15.0	26.9	15.0	14.0		15.0	13.0		15.0	12.0
20.0	26.8	20.0	12.8		20.0	12.0		20.0	11.0
25.0	26.5	25.0	12.0		25.0	11.0		25.0	10.8
30.0	26.0	30.0	11.5		30.0	10.8		30.0	10.5
40.0	25.0	40.0	10.3		40.0	10.0		40.0	9.9

TABLE 44

EFFECT OF THREE CAT FLOC SAMPLES ON THE SETTLING RATE OF ACTIVATED SLUDGE FROM
THE UNIVERSITY OF FLORIDA SEWAGE TREATMENT PLANT; POLYMER DOSE 10.0 mg/l

Suspended Solids 1,500 mg/l									
SVI 630									
Blank		Cat Floc No. 1			Cat Floc No. 2			Cat Floc No. 3	
Time Min.	Sludge Depth Inches	Time Min.	Sludge Depth Inches	Time Min.	Time Min.	Sludge Depth Inches	Time Min.	Sludge Depth Inches	Time Min.
0.0	27.0	0.0	27.0	0.0	0.0	27.0	0.0	27.0	0.0
2.0	27.0	2.0	25.0	2.0	2.0	23.0	2.0	22.5	2.0
4.0	27.0	4.0	21.5	4.0	4.0	18.5	4.0	17.5	4.0
6.0	26.9	6.0	18.5	6.0	6.0	15.0	6.0	14.5	6.0
8.0	26.9	8.0	16.5	8.0	8.0	13.5	8.0	13.0	8.0
10.0	26.8	10.0	15.0	10.0	10.0	12.5	10.0	12.5	10.0
15.0	26.8	15.0	13.0	15.0	15.0	11.0	15.0	10.8	15.0
20.0	26.7	20.0	11.5	20.0	20.0	10.3	20.0	10.3	20.0
25.0	26.0	25.0	11.0	25.0	25.0	9.9	25.0	9.8	25.0
35.0	25.0	35.0	10.0	35.0	35.0	9.5	35.0	9.3	35.0
40.0	23.5	40.0	9.5	40.0	40.0	9.3	40.0	9.0	40.0

TABLE 45
EFFECT OF THREE CAT FLOC SAMPLES ON THE SETTLING RATE OF ACTIVATED SLUDGE FROM
THE UNIVERSITY OF FLORIDA SEWAGE TREATMENT PLANT; POLYMER DOSE 20.0 mg/l

Suspended Solids 1,500 mg/l						
SVI 520						
Blank						
Cat Floc No. 1			Cat Floc No. 2			Cat Floc No. 3
Time Min.	Sludge Depth Inches	Time Min.	Sludge Depth Inches	Time Min.	Sludge Depth Inches	Time Min. Sludge Depth Inches
0.0	27.0	0.0	27.0	0.0	27.0	0.0 27.0
2.0	27.0	2.0	25.8	2.0	23.0	2.0 23.5
4.0	27.0	4.0	23.0	4.0	19.0	4.0 17.0
6.0	27.0	6.0	20.0	6.0	16.0	6.0 14.0
8.0	26.9	8.0	18.0	8.0	13.8	8.0 12.3
10.0	26.9	10.0	16.8	10.0	12.5	10.0 11.5
15.0	25.5	15.0	14.0	15.0	10.6	15.0 10.3
20.0	24.0	20.0	12.0	20.0	10.0	20.0 9.6
25.0	22.5	25.0	11.0	25.0	9.5	25.0 9.0
30.0	21.0	30.0	10.5	30.0	9.3	30.0 8.9
40.0	19.0	40.0	9.5	40.0	8.8	40.0 8.5

TABLE 46
EFFECT OF THREE CAT FLOC SAMPLES ON THE SETTLING RATE OF ACTIVATED SLUDGE FROM
THE UNIVERSITY OF FLORIDA SEWAGE TREATMENT PLANT; POLYMER DOSE 40.0 mg/l

Suspended Solids 1,500 mg/l						
SVI 590						
Blank						
Cat Floc No. 1			Cat Floc No. 2			Cat Floc No. 3
Time Min.	Sludge Depth Inches	Time Min.	Sludge Depth Inches	Time Min.	Sludge Depth Inches	Time Min.
0.0	27.0	0.0	27.0	0.0	27.0	0.0
2.0	27.0	2.0	26.0	2.0	24.5	2.0
4.0	27.0	4.0	25.3	4.0	22.0	4.0
6.0	27.0	6.0	24.0	6.0	18.0	6.0
8.0	27.0	8.0	22.0	8.0	16.0	8.0
10.0	26.9	10.0	20.5	10.0	14.0	10.0
12.0	26.9	12.0	19.0	12.0	13.0	12.0
15.0	26.9	15.0	17.0	15.0	11.9	15.0
20.0	25.5	20.0	14.8	20.0	10.5	20.0
25.0	25.5	25.0	13.5	25.0	9.9	25.0
30.0	24.0	30.0	12.5	30.0	9.5	30.0
40.0	22.5	40.0	11.0	40.0	8.9	40.0
						8.5

TABLE 47

EFFECT OF VARIOUS DOSAGES OF CAT FLOC NO. 1 ON THE
DEWATERING OF AN ANAEROBICALLY DIGESTED SLUDGE FROM
THE UNIVERSITY OF FLORIDA SEWAGE TREATMENT PLANT;
FILTER LEAF TEST; SLUDGE SOLIDS 1.5 PERCENT

Polymer Dosage % of Dry Solids	Dry Cake grams/ft ²	Wet Cake % Solids	Filtrate ml
0.00	1	15	50
0.33	14	22	290
0.50 ;	15	21	315
0.60	16	20	290
0.67	17	22	340
0.73	19	16	275
0.83	19	22	. .
0.87	17	24	260
1.00	16	24	260
1.33	15	23	235

TABLE 48

EFFECT OF VARIOUS DOSAGES OF CAT FLOC NO. 2 ON THE
DEWATERING OF AN ANAEROBICALLY DIGESTED SLUDGE FROM
THE UNIVERSITY OF FLORIDA SEWAGE TREATMENT PLANT;
FILTER LEAF TEST; SLUDGE SOLIDS 1.5 PERCENT

Polymer Dosage % of Dry Solids	Dry Cake grams/ft ²	Wet Cake % Solids	Filtrate ml
0.00	1	15	50
0.17	10	15	250
0.33	25	17	410
0.43	29	18	520
0.50	30	16	545
0.57	31	18	580
0.67	30	16	615
0.83	22	13	575
1.00	21	23	460

TABLE 49

EFFECT OF VARIOUS DOSAGES OF CAT FLOC NO. 3 ON THE
DEWATERING OF AN ANAEROBICALLY DIGESTED SLUDGE FROM
THE UNIVERSITY OF FLORIDA SEWAGE TREATMENT PLANT;
FILTER LEAF TEST; SLUDGE SOLIDS 1.5 PERCENT

Polymer Dosage % of Dry Solids	Dry Cake grams/ft ²	Wet Cake % Solids	Filtrate ml
0.00	1	15	50
0.17	10	19	280
0.33	30	16	530
0.43	35	15	580
0.50	38	18	660
0.57	36	16	660
0.67	34	17	620
0.83	25	20	500

TABLE 50

EFFECT OF VARIOUS DOSAGES OF CAT FLOC NO. 1 ON THE
DEWATERING OF AN ANAEROBICALLY DIGESTED SLUDGE FROM
THE UNIVERSITY OF FLORIDA SEWAGE TREATMENT PLANT;
FILTER LEAF TEST; SLUDGE SOLIDS 3.0 PERCENT

Polymer Dosage % of Dry Solids	Dry Cake grams/ft ²	Wet Cake % Solids	Filtrate ml
0.00	2	14	20
0.08	14	17	50
0.17	21	16	75
0.25	32	15	125
0.33	36	15	130
0.42	43	16	180
0.50	53	17	190
0.58	43	17	220
0.67	45	19	230
0.83	46	18	240
1.00	37	21	220
1.33	35	17	180

TABLE 51

EFFECT OF VARIOUS DOSAGES OF CAT FLOC NO. 2 ON THE
DEWATERING OF AN ANAEROBICALLY DIGESTED SLUDGE FROM
THE UNIVERSITY OF FLORIDA SEWAGE TREATMENT PLANT;
FILTER LEAF TEST; SLUDGE SOLIDS 3.0 PERCENT

Polymer Dosage % of Dry Solids	Dry Cake grams/ft ²	Wet Cake % Solids	Filtrate ml
0.00	2	14	20
0.17	20	16	80
0.25	31	16	140
0.33	50	16	280
0.42	59	15	330
0.50	50	19	330
0.67	40	21	340
1.00	32	21	220
1.33	31	22	170

TABLE 52

EFFECT OF VARIOUS DOSAGES OF CAT FLOC NO. 3 ON THE
DEWATERING OF AN ANAEROBICALLY DIGESTED SLUDGE FROM
THE UNIVERSITY OF FLORIDA SEWAGE TREATMENT PLANT;
FILTER LEAF TEST; SLUDGE SOLIDS 3.0 PERCENT

Polymer Dosage % of Dry Solids	Dry Cake grams/ft ²	Wet Cake % Solids	Filtrate ml
0.00	2	14	20
0.17	19	16	93
0.25	35	17	220
0.28	62	. .	. .
0.33	78	17	370
0.37	72	16	400
0.42	71	15	400
0.50	62	16	430
0.67	55	19	400
1.00	52	20	330
1.33	34	24	220

TABLE 53

EFFECT OF VARIOUS DOSAGES OF CAT FLOC NO. 1 AND NO. 2 ON
THE SPECIFIC RESISTANCE OF AN ANAEROBICALLY DIGESTED
SLUDGE FROM THE UNIVERSITY OF FLORIDA SEWAGE
TREATMENT PLANT; SLUDGE SOLIDS 3.0 PERCENT

Polymer Dosage % of Dry Solids	Cat Floc No. 1	Cat Floc No. 2
	r^* sec^2/gm	r^* sec^2/gm
0.00	2.05×10^{10}	2.05×10^{10}
0.17	. .	5.83×10^8
0.33	5.46×10^8	7.37×10^7
0.50	1.84×10^8	5.14×10^7
0.67	1.53×10^8	5.75×10^7
0.83	1.53×10^8	5.95×10^7
1.00	1.57×10^8	. .
1.17	2.17×10^8	1.08×10^8
1.50	3.14×10^8	. .
1.67	. .	1.45×10^8
2.00	3.89×10^8	. .

*Specific resistance.

TABLE 54

EFFECT OF VARIOUS DOSAGES OF CAT FLOC NO. 3 and DOW C-31
ON THE SPECIFIC RESISTANCE OF AN ANAEROBICALLY DIGESTED
SLUDGE FROM THE UNIVERSITY OF FLORIDA SEWAGE
TREATMENT PLANT; SLUDGE SOLIDS 3.0 PERCENT

Polymer Dosage % of Dry Solids	Cat Floc No. 3 r* sec ² /gm	Dow C-31 r* sec ² /gm
0.00	2.05×10^{10}	2.05×10^{10}
0.17	6.83×10^8	. .
0.33	7.24×10^7	5.80×10^9
0.50	4.80×10^7	. .
0.67	3.69×10^7	2.68×10^9
0.83	5.76×10^7	. .
1.00	6.59×10^7	. .
1.33	8.19×10^7	4.69×10^8
2.00	1.57×10^8	1.51×10^8
2.67	. .	7.69×10^7
3.33	. .	5.68×10^7
4.00	. .	4.73×10^7
4.67	. .	4.35×10^7
5.33	. .	7.23×10^7
6.67	. .	6.20×10^7
8.33	. .	1.48×10^8

*Specific resistance.

APPENDIX B

**A METHOD FOR THE DETERMINATION OF THE UNIT AREA
OF AN ACTIVATED SLUDGE PLANT SECONDARY CLARIFIER**

A METHOD FOR THE DETERMINATION OF THE UNIT AREA OF AN ACTIVATED SLUDGE PLANT SECONDARY CLARIFIER

The size of secondary clarifiers in the activated sludge process is determined by three factors;⁶⁴

1. The area required for clarification over the complete range of mixed liquor suspended solids that may be handled. This area is related to the allowable overflow rate, in order that the vertical liquid rise rate at any level is less than the solids subsidence rate at that level.

2. The area and volume requirements to produce by thickening an underflow of a desired concentration.

3. The maximum permissible retention time that a biological sludge may remain in the clarifier without floating to the top due to gas formation from anaerobic digestion.

In any particular situation the clarifier area and volume will be controlled by one of these three factors.

The area required to provide the proper overflow rate for clarification is computed from the free settling velocity of the sludge. The settling velocities of a

range of mixed liquor suspended solids must be determined and the minimum settling velocity used to determine an area such that the sludge subsidence is greater than the rate of liquid rise. Settling velocities are determined graphically from laboratory settling curves as shown in Fig. 48. The slope of line XY is the free settling velocity of that particular sludge. The laboratory method for determining such a settling curve has previously been discussed in Chapter III.

The area required to produce by thickening an underflow of a desired concentration is computed with a relationship developed from a rational analysis of the behavior of a suspension undergoing batch sedimentation.^{64,86,87} Initially, the concentration is the same throughout the suspension, and the solids settle at a uniform velocity. The solids must pass through all concentrations ranging from the initial concentration to that of the deposited solids before they reach the bottom of the settling column. If, at any of these intermediate concentrations, the solids-handling capacity is less than that at the lower concentration occurring immediately above it in the vessel, a zone of such intermediate concentration will start building up, since the solids cannot pass

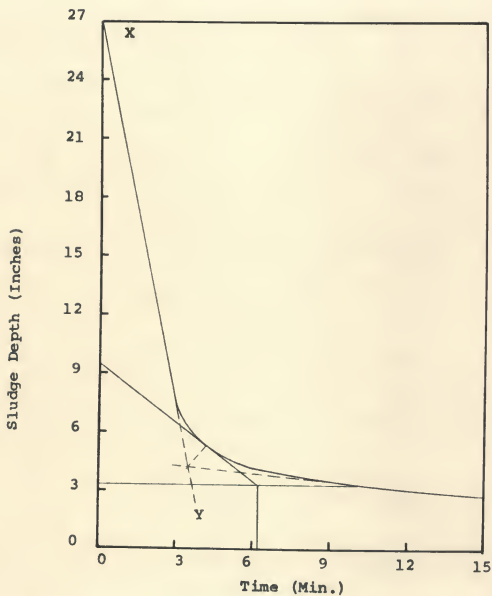


Fig. 48. Interface Settling Curve.

through it as fast as they are settling down into it.

Kynch⁸⁶ showed that the rate of upward movement of such a constant concentration zone is uniform. Consider an infinitely thin layer at the top of such a zone, having a concentration C , originating at the bottom at time zero and moving upward at a velocity U (see Fig. 49). The

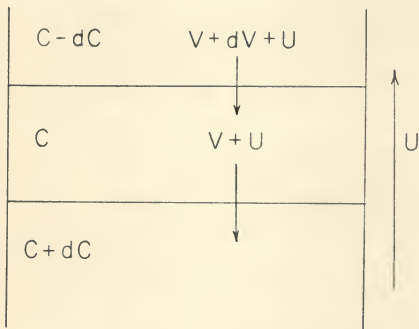


Fig. 49. Definition Sketch of a Concentration Layer Rising Through a Settling Column.

solids settling into this layer came from a layer having a concentration of $(C - dC)$ and a settling velocity with respect to the column of $(V + dV)$ but with respect to the

layer of $(V + dV + U)$. The solids settle out of the layer at a velocity of V with respect to the column and $(V + U)$ with respect to the layer. Since the concentration of the layer C remains constant, the quantity of solids settling into the layer must equal the quantity of solids settling out of the layer:

$$(C - dC)At(V + dV + U) = CA t(V + U) \quad (1)$$

where A = cross-section area perpendicular to direction of solids movement

t = time

By simplifying and solving for U , dropping out infinitesimals of the second order,

$$U = C \frac{dV}{dC} - V \quad (2)$$

Since, according to the Kynch⁸⁶ postulate $V = f(C)$, it can be seen that

$$\frac{dV}{dC} = f'(C)$$

$$U = C f'(C) - f(C) \quad (3)$$

The concentration of the layer under consideration remains constant and, since $f(C)$ and $f'(C)$ have fixed values, U must also be constant. The constancy of U may now be used to determine the solids concentration of the layer at the upper boundary of a settling sludge.

If a column of height H_0 is filled with a suspension having a uniform concentration of C_0 , the total weight of sludge in the suspension is equal to $C_0 H_0 A$. When any capacity-limiting concentration layer reaches the pulp-water interface, all solids in the column must have passed through it, since it was propagated from the bottom of the column upward. If the time required for a layer of concentration C_2 to reach the interface is t_2 , then the quantity of solids having passed through the layer is $C_2 A t_2 (V_2 + U_2)$, which will be equal to the total weight of the solids in the column.

$$C_0 H_0 A = C_2 A t_2 (V_2 + U_2) \quad (4)$$

It has been proved that the upward velocity of any specific layer is constant. Then if H_2 represents the height of the interface at time t_2 ,

$$U_2 = \frac{H_2}{t_2} \quad (5)$$

By substituting this expression into Equation 4 and simplifying,

$$C_2 = \frac{C_0 H_0}{H_2 + V_2 t_2} \quad (6)$$

A plot of the interface height as a function of time is shown in Figure 50. V_2 is equal to dH/dt at the

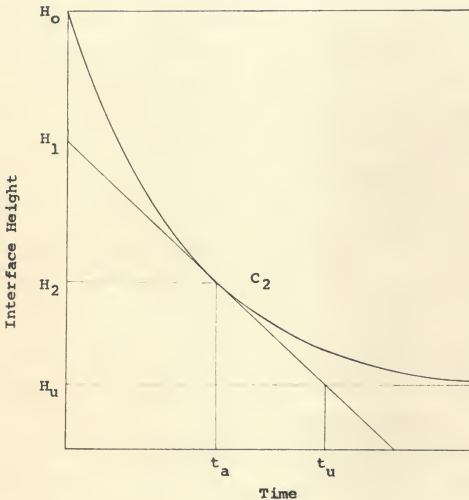


Fig. 50. Interface Height as a Function of Time
(from Talmadge and Fitch⁸⁷).

point along the curve when a layer having a concentration C_2 comes to the surface of the sludge. V_2 is then the slope of the tangent to the curve at $(H_2 t_2)$. It follows mathematically that the intercept of this tangent on the H axis is $H_2 + V_2 t_2$ (shown as H_1). By substituting H_1 for

$H_2 + V_2 t_2$ in Equation 6, it is shown that $C_2 H_1 = C_0 H_0$.

Therefore, H_1 is the height the sludge would occupy if all the solids were at the same concentration as the sludge water interface. For any value of C_2 the corresponding value of H_1 can be calculated.

In a continuously operated clarifier, the position of the liquid-solids interface is relatively static.

Therefore, if the solids at this interface are assumed as a datum, water is passing the solids at a bulk rate of $A(H_1 - H_2)/t_2$. All of the liquid will not move through the interface, as a portion will accompany the solids to the underflow. The actual volume of liquid passing upward through the interface is equal to the volume which would be released as the concentration of the solids changes from the interface concentration C_2 to that of the underflow C_u . In a batch analysis this volume would be $A(H_1 - H_u)$ where H_u is the height of the sludge interface if all the solids in the system were at an underflow concentration of C_u .

The time that would be required to release

$A(H_1 - H_u)$ through a layer of concentration C_2 would then be

$$t' = \frac{\text{amount of water to eliminate}}{\text{rate of eliminating water}} = \frac{A(H_1 - H_u)}{\frac{A(H_1 - H_2)}{t_2}} \quad (7)$$

$$\frac{t'}{H_1 - H_u} = \frac{t_2}{H_1 - H_2} \quad (8)$$

From Fig. 50 it is seen that

$$t' = t_u \quad (9)$$

The total quantity of solids in the batch test is $C_0 H_0 A$, and it would take time t_u for this quantity of solids to subside past a layer of concentration C_2 in a continuous clarifier. Therefore, equating the rate of solids input with the rate at which the solids can pass through the layer,

$$qC_0 = \frac{C_0 H_0 A}{t_u} \quad (10)$$

and

$$A = \frac{qt_u}{H_0} \quad (11)$$

where

A = cross section required for a layer with concentration of C_2 , ft^2

q = volumetric flow rate of suspension entering thickener, ft^3/sec

t_u = time required to attain underflow concentration C_u , sec

H_0 = initial height of interface in settling column, ft

Plots similar to Fig. 50 may be used to graphically determine the required area corresponding to any sludge

concentration C_2 in the free settling range.⁸⁷ A straight line is drawn through C_2 tangent to the settling curve. The intersection of the tangent with the line representing the desired underflow concentration C_u determines t_u , from which the required area may be computed.

The sludge concentration that requires the largest cross-section area is the critical concentration which controls the solids-handling capacity of the system. This concentration usually is found in the transition zone at the point where compression begins. Rich⁸⁸ estimates this point by bisecting the angle formed where tangents from the hindered settling zone and the compression zone intersect. The bisector cuts the settling curve near the point of compression.

When the underflow line, H_u , intersects the settling curve above the compression point, the time, t_u , will be the coordinate of the intersection, since any other tangent will intersect the underflow line at a lesser value of t_u .

An example calculation of determining the required area for an activate sludge clarifier is presented below.

Example:

A laboratory batch settling test conducted in a 27-inch by 6-inch settling column using a sludge having a

solids concentration of 1,000 mg/l yielded the following results:

<u>Time (Min.)</u>	<u>Sludge Height (Inches)</u>
1.0	19.5
2.0	14.6
3.0	7.5
4.0	5.5
5.0	4.6
6.0	4.1
9.0	3.5
12.0	3.0
15.0	2.8

The data were plotted to give the curve in Fig. 48. The assumed flow into the continuous clarifier is 1 ft³/sec. An underflow concentration of 8,000 mg/l is desired.

1. Determine height of sludge interface if all solids in the system are at the underflow concentration

$$H_u = 8,000 \text{ mg/l}$$

$$H_u = \frac{C_o}{C_u} H_o = \frac{1,000}{8,000} 27 = 3.38 \text{ inches}$$

A horizontal line is drawn at this height (see Fig. 48).

2. Estimate the compression point by bisecting the angle formed by the tangents of the two end portions

of the subsidence curve. Next a straight-line tangent to the curve at the compression point is constructed. This line intersects the underflow line at $t_u = 6.3$ min.

3. The area required for thickening is computed by Equation 11.

$$A = \frac{qt_u}{H_o} = \frac{1 \times 6.3 \times 60}{27/12} = 168 \text{ ft}^2$$

4. From the free settling portion of the curve, the rate of subsidence is found to be

$$S_r = \frac{27/12}{4 \times 60} = 9.38 \times 10^{-3} \text{ ft/sec}$$

5. The area required for clarification is

$$A = \frac{q}{S_r} = \frac{1(23.62/27)}{9.38 \times 10^{-3}} = 94 \text{ ft}^2$$

6. From this it can be seen that, in order to have an underflow concentration of 8,000 mg/l, an area of 168 ft² must be provided.

It should be noted that, since the rate of sludge settling in the free zone is a function of solids concentrations, laboratory settling tests must be conducted using a wide range of suspended solids concentrations in order to determine the minimum settling rate which will be used for calculating the unit area for clarification. A special

case which should be mentioned is a suspension characterized by a period of very slow flocculation, followed by more rapid flocculation, then settling. In this situation not only must enough area be provided for thickening and clarification but sufficient detention time must be provided for the sludge to flocculate and begin settling.

APPENDIX C

SAMPLE CALCULATION OF THE DETERMINATION
OF THE SPECIFIC RESISTANCE OF AN
ANAEROBICALLY DIGESTED SLUDGE

SAMPLE CALCULATION OF THE DETERMINATION
OF THE SPECIFIC RESISTANCE OF AN
ANAEROBICALLY DIGESTED SLUDGE

Carman as discussed by Coackley⁷² has shown that filtration in the case of compressible filter cakes is:

$$\frac{dV}{d\theta} = \frac{PA^2}{\mu(rcV + RmA)} \quad (1)$$

V = volume of filtrate, ml

θ = time, sec

P = pressure, inches Hg

A = filtration area, cm²

μ = filtrate viscosity, poises

r = specific resistance, sec²/gm

c = weight of solids/unit volume of filtrate, gm/ml

Rm = initial resistance of a unit area of filtering surface

The specific resistance, r, is numerically equal to the pressure difference required to produce a unit rate of filtrate flow of unit viscosity through a unit weight of cake.

Integration of Equation 1 yields:

$$e = \frac{\mu_{rc}}{2PA^2} \cdot V^2 + \frac{\mu_{Rm}}{PA} \cdot V \quad (2)$$

or

$$\frac{e}{V} = \frac{\mu_{rc}}{2PA^2} \cdot V + \frac{\mu_{Rm}}{PA}$$

i.e.,

$$\frac{e}{V} = bV + a$$

If $\frac{e}{V}$ is plotted against V , a straight line of slope b is obtained where

$$b = \frac{\mu_{rc}}{2PA^2}$$

To calculate the specific resistance, it is necessary to obtain data to plot $\frac{e}{V}$ against V so that b may be measured. This is done as described in Chapter III. Once slope b has been determined, and as the other variables are known, the specific resistance may be calculated from the equation:

$$r = \frac{2bPA^2}{\mu_c}$$

The example calculation is based on a filtration test on the effect of 100 mg/l of Cat Floc No. 1 on dewatering of an anaerobically digested sludge from the University of Florida sewage treatment plant.

Method of Calculating Specific Resistance

A graph of $\frac{\theta}{V}$ against V is plotted (see Fig. 51). The value of V used is the corrected value found by subtracting the volume of liquid obtained while the cake is being formed from the following volume readings. Slope b is in the units of sec per cm^6 , the filtrate viscosity is poises, area in cm^2 , filtration pressure in gm per sq cm, and solids content in gm dry solid per ml liquid before filtration.

From laboratory test:

<u>θ (sec)</u>	<u>Vol. Filtrate (ml)</u>	<u>Corrected V</u>	<u>$\frac{\theta}{V}$</u>
0	20	0	. .
30	57	37	0.81
60	76	56	1.07
90	90	70	1.28
120	112	92	1.30
180	124	104	1.73
210	130	110	1.91
240	138	118	2.04
270	146	126	2.14

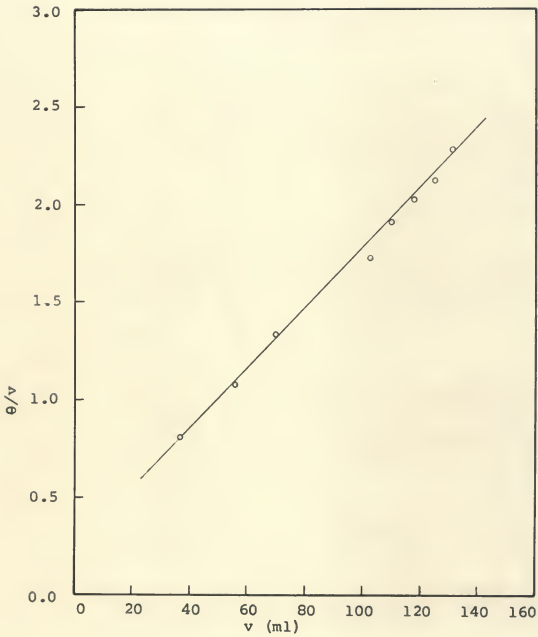


Fig. 51. Effect of 100 mg/l of Cat Floc No. 1 on Dewatering of an Anaerobically Digested Sludge from the University of Florida Sewage Treatment Plant. Sludge Solids 3.0 Percent.

Filtration pressure = 20.0 in Hg = 674 gm/cm²

Filtration viscosity = 0.0110 poises

Solids content c = 0.03 gm/ml

Filter area A = 95 cm²

Slope b = 0.0148 sec/cm⁶

$$r = \frac{(2) (674) (95)^2 (0.0148)}{(0.0110) (0.03)}$$

$$= 5.46 \times 10^8 \text{ sec}^2/\text{gm}$$

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BIOGRAPHICAL SKETCH

Richard Henry Jones was born on January 21, 1939, in Starkville, Mississippi. He attended primary and secondary schools in Starkville, and entered Mississippi State University in September of 1957. Mr. Jones was graduated from Mississippi State University in June, 1961, with the degree of Bachelor of Science in Civil Engineering. He obtained a United States Public Health Service Traineeship in order to pursue his graduate work at the University of Florida and obtained his Master of Science degree in Engineering in April, 1963. From September, 1963, until August, 1964, he worked as Sanitary Engineer with the Florida State Board of Health in Winter Haven, Florida. Since September, 1964, he has been at the University of Florida continuing his studies in the Graduate School toward his doctorate degree.

This dissertation was prepared under the direction of the chairman of the candidate's supervisory committee and has been approved by all members of that committee. It was submitted to the Dean of the College of Engineering and to the Graduate Council, and was approved as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

December 17, 1966

J. A. Arthur
Dean, College of Engineering

Dean, Graduate School

Supervisory Committee:

C. P. Black
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